CRANFIELD UNIVERSITY

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The Development of Machine Algorithms for the Cranfield Underwater Laser Stripe Imaging System

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

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ABSTRACT

When using conventional illumination in the underwater environment, the greatest problem faced has always been that of back-scatter. This reduces visual quality both to the naked eye and through the use of underwater cameras. This project continues research into a hybrid underwater laser viewing system, combining a laser scanning technique with conventional underwater viewing system technology.

The use of carefully positioned lighting can greatly reduce the problem of back-scattered light, improving image definition and contrast. With the use of a laser light source this can be improved even further within a more flexible system. Utilising two scanning devices a narrow stripe of light can be formed which is scanned over a target area. Small successive regions of any object lying within that area can then be illuminated, isolated and extracted using image processing to compile a complete image of the object.

For the purposes of surf zone and shallow water mines counter measures, the system requires reliable machine algorithm based image processing techniques, to compile a constructed image of target objects within highly turbid regions. Projected stripes take on various characteristics dependent on the geometry and aspect of the object which they fall upon and the conditions experienced. High levels of turbidity leading to significant noise, creates considerable difficulties in the isolation of the stripe region and the extraction of meaningful visual information. The success of any technique would rely upon the overcoming of these difficulties, allowing the system to offer the operator the most useful visual information permissible in the final compilation of the image.

Through various image processing techniques these factors have been tackled and their effects on the final image, greatly reduced. The result is the creation of highly stable and effective processing techniques allowing improved object definition and recognition, in levels of high turbidity.

ACKNOWLEDGEMENTS

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- And finally to my little girl Anna; thank you for being so good and so patient and letting Daddy work. I promise I will take you to the park now.

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α	Volume attenuation coefficient (m^{-1})
θ	Angle
γ	Gamma coefficient
s	Second
p/s	Per second
mm	Millimetres

1 INTRODUCTION

Capturing an optical image of a target object in the underwater environment has always been a positive tool for those operating sub-sea. The limitations of imaging systems however have restricted their use. Sub-sea industries are pushing back the boundaries and in doing so, demanding more from technology. There are many tasks that are required to be carried out beyond the safe deployment of human divers and to fill the gap we have looked to Remotely Operated Vehicles or ROVs. These vehicles are finding a wide range of applications both within marine industries and non-commercial practices. Their applications range from simple observation platforms to precision seabed surveys and manipulative tasks.

Their effective use though requires skilful operators working from the surface, who are capable not only of manoeuvring the vehicle into position whilst avoiding obstacles, but who are also able to perform often complicated and precise tasks. This requires the operator to have sufficient visual information of the target area from an optical system mounted on the ROV or in close proximity.

Underwater optical systems though are restricted greatly by the environment in which they are operated; visibility is often as low as half a metre. Even distilled water attenuates light considerably limiting horizontal visibility. Such attenuation is on the whole due to two particular factors; absorption and scattering events. Dissolved and suspended particles in the water column will increase the attenuation effects of these factors.

Oceans, lakes and rivers, indeed all natural bodies of water contain particles in suspension. These minute pieces of matter are comprised of various substances such as sand, plankton, vegetation and air bubbles. When a source of light is used, the light reflects and deflects off the surfaces of these suspended particles, causing the light to diffuse and scatter. At its most severe, when the diffused light partially obscures the target object, it is known as backscatter. Whatever the scale of this backscatter, it detracts from the "cleanliness" of the images and distracts the viewing eye from the subject in frame. Therefore when using imaging systems underwater, backscatter should be reduced wherever possible.

Coastal and surf zone waters in general experience far greater attenuation levels. These waters often exhibit a green appearance due to the presence of certain materials known as 'Yellow Substances' and can be traced to compounds of plant and animal materials. These substances strongly absorb light within the blue spectral region causing a move of the spectral peak towards green.

When an artificial light source is used to illuminate a target, light is lost due to absorption and scattering, both between the light source and the target and between the target and the camera. As a result both the image brightness and contrast are reduced affecting the quality of the final image achieved. Selective colour absorption causes all wavelengths outside of the blue green spectrum to be greatly attenuated.

In standard underwater imaging systems problems occur in several areas between the light source, the target and the receiving camera:

- Light from the source is lost due to scattering preventing this light from reaching the target.
- Light from the source is also lost due to absorption as photons are converted into other forms of energy thus preventing light reaching the target.
- Backscatter further prevents the light reaching the target from the source and can reduce contrast on the received image.
- When the light is reflected off the target light is lost once again due to these three factors.

A further factor to be considered is that light from the source does not always reach the receiving camera via the target. Backscattering effects contain no object information but degrade the contrast of the image. Forward scattering events can also affect the final image, by having once reached the target object and then undergoing scattering on its return to the receiving camera. This can reduce image resolution, reducing the sharpness of an image.

Contrast and power must be considered in determining the limits of underwater illumination of a target, each will limit the efficiency of an underwater viewing system. If the reduction of image quality is due predominately to the level of backscattered light then this is considered to be 'contrast limited'. Alternatively a low level of light may be reaching the object despite image contrast being high; in this case the imaging system is said to be 'power limited'. Increasing the intensity of the light source though, may not improve imaging range as increased backscatter intensity will consequently be proportional. [1.1]

To overcome the difficulties created by backscatter several different methods have been devised offering varying improvement in image quality. Examples of these are light source positioning techniques, including camera to light separation and light behind camera techniques, light polarization and the use of monochromatic light sources.

Amongst these monochromatic sources are the uses of laser based imaging techniques such as Laser Line Scanners (LLS). One such example has been developed at Cranfield University. Since 1990 research has been ongoing into the development of a hybrid underwater laser viewing system combing the laser scanning technique with conventional underwater viewing system technology.

The use of carefully positioned lighting can greatly reduce the problem of backscattering, improving image definition and contrast. With the use of a laser light source this can be improved even further within a more flexible system. A narrow laser stripe is formed by a scanning device, with a second scanning device allowing the stripe to be moved on the vertical plane. In this form only part of the target is illuminated and with the use of image processing these individual parts can be isolated and extracted in quick succession allowing the target image to be constructed.

This is a process that was originally proposed in the 1980's for use in oceanographic surveys to increase the number of attenuation lengths over which an image could be achieved, but using conventional lighting sources due to the high cost of laser sources at the time. Despite this, viewing distances of 5-7 attenuation lengths were suggested through computer simulations [(1.2)]. The cost of powerful lasers within the green spectral wavelength are now far more affordable allowing an improved stripe construction which can be scanned across the target area and mounted on a stationary platform.

With this system a conventional SIT camera can be used as a receiver, this means low cost and a high level of adaptability to stationary platforms such as an ROV. Further the distance to the target is not needed unlike other laser imaging systems that require the range to be found.

The scanning stripe is projected through the water column until it is reflected by an object. In reality due to particles within the water column, a large level of light is reflected back. This creates noise on the received image and as a result, target clarity is greatly reduced with increased turbidity. Unlike other laser vision devices that process spot mapping techniques or multiple stripes, the Cranfield system only requires the processing of a single isolated stripe. Overall processing time is then cut for the creation of the image allowing close to real time imaging to be achieved.

In 1996 the Cranfield University, Department of Marine Technology and the Defence Evaluation and Research Agency (DERA) Bincleaves, combined on the development of the system for deployment on DERA's Non Acoustic Sensor Platform (NASP)(see figure 1.1) and more recently on the Enhanced Sensor Platform (ESP) (see figure 1.2). These vehicles were and are being developed for use in mine counter measures in shallow water and surf zone regions.

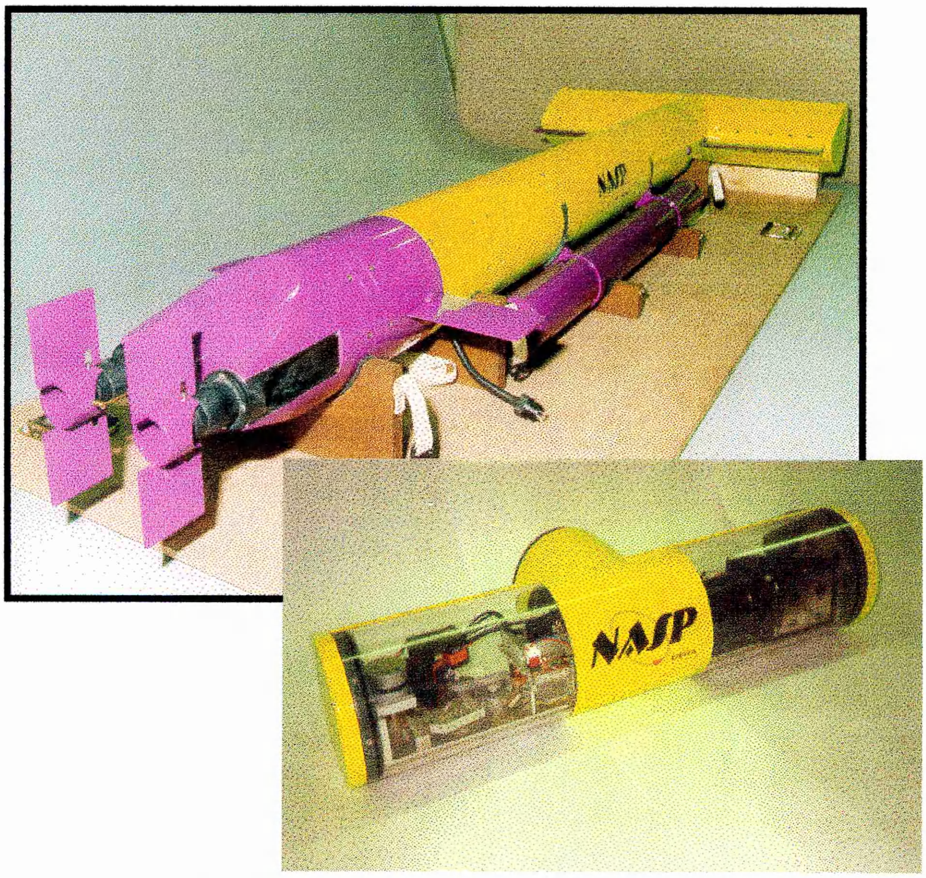


Figure 1.1: NASP Surf zone mine detection system (courtesy of DERA Bincleaves)

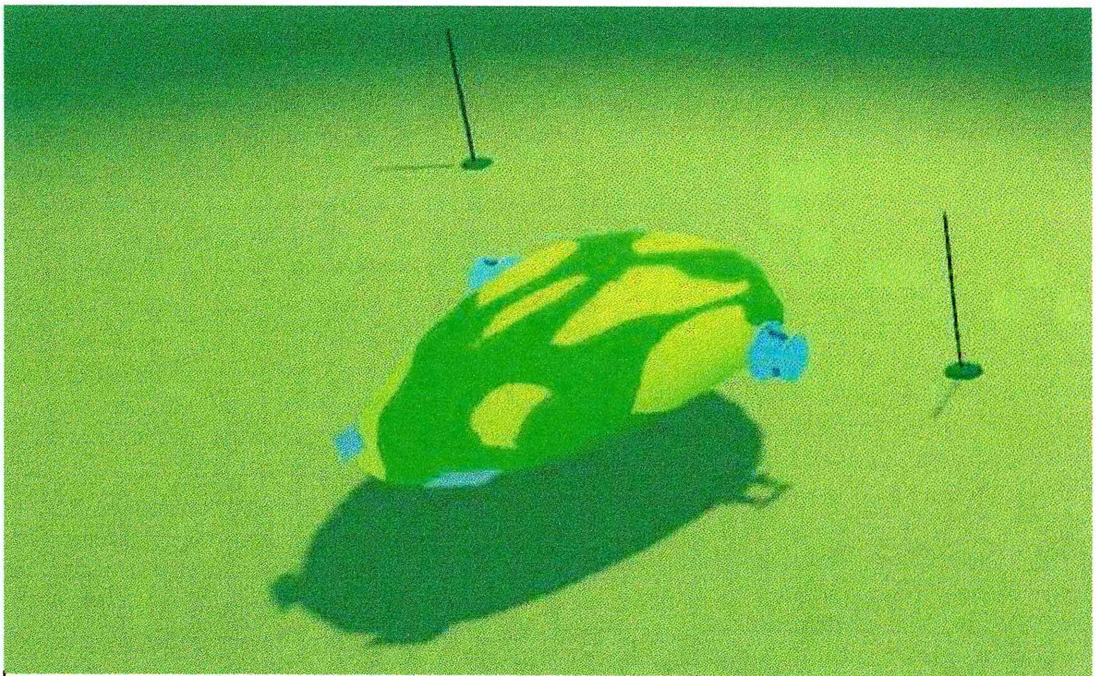


Figure 1.2: ESP Surf zone mine detection system (courtesy of DERA Bincleaves)

The requirements for ROV/AUV based surf zone and shallow water mine-hunting present's particular challenges for underwater optical imaging systems. These are;

1. Improvement on detail obtained through other systems incorporated on the vehicle.
2. Improved ability for recognition, of mines over mine like objects, through the enhancement of geometric and suface features.
3. Maintain covert status in the theatre.
4. Ability to transfer information to base vessel.

This thesis describes the development of stable and effective machine algorithm based imaging techniques to be used in conjunction with the Cranfield Laser Stripe Imaging System. These techniques would allow the laser stripe that is projected onto a target object in the water, to be isolated, extracted and compiled. This in a manner that provides the operator with sufficient information to identify a target object in raised turbidity levels.

The development of these algorithms was carried out to meat the requirements of the sponsors, The Defence Evaluation and Research Agency (DERA). Imaging of target objects was required in low to light absent conditions allowing a covert solution to mine hunting in shallow water and surf zone regions.

2 BACKGROUND

2.1 MINES; THE THREAT

"As we look to future joint littoral warfare and the challenge that will face our 'warfighters', there is little doubt that naval mines will be among the asymmetric threats of most concern."[(2.1)]

When we consider the use of mines in the sea we are drawn to the images of numerous war films where massive footballs covered with pointy arms, floating ominously in the water for on-coming ships. The engineering of sea mines though has moved on dramatically from these cumbersome, imprecise and relatively cheap weapons.

Military analysts are predicting the future of mine warfare will move significantly in the direction of a very shallow water and surf zone (VSW/SZ) regions. Such use of mines will deny invading forces possible landing zones and so hamper any invasion. The use of personnel for mine counter-measures (MCM) presents extreme dangers and the risk of losing these personnel. Therefore it is in the direction of remotely operated vehicles (ROVs') and autonomous underwater vehicles (AUVs') that potential aggressive forces/peacekeeping forces are looking.

Throughout its history the sea mine has proven to be a valuable part of any military arsenal. When used effectively, they can provide a round the clock cost effective weapon, needing little manpower in relation to its defensive capabilities. In times of conflict, it is a primary weapon for states that face a threat over bodies of water. Sea mines provide a sizable and dangerous challenge to combatants that must overcome these obstacles.

In the early nineties the onset of the Gulf war opened the eyes of military planners to various problems. In particular were the problems associated with the detection and classification of mines in the 0 - 10 m water depth region. These regions are generally referred to as the very shallow water and surf zone regions. Prior to the Normandy landings in 1944 great emphasis had been put on to the overcoming of beach defences deployed by the German army in these regions. Since then the technology applied to such defences has moved on considerably.[(2.2)]

The conflict in the Gulf highlighted the advancements that had been made, with the threat of smaller more discreet mines, with low acoustic cross-sections being utilised in VSW/SZ regions. The use of sonar systems for detection of these threats outlined their inherent reverberation problems when used in these regions and showed the need to use alternative techniques. [(2.2)]

Naval mines, unlikely as it may seem, fall into the same category as nuclear weapons. They are a deterrent in nature and are used in defensive form. Their use in the Second World War and subsequent conflicts showed their increasing role in the performance of operational and strategic missions. Sea mines are an efficient, reliable and a relatively low cost weapon.

The development of sea mines is towards precision weapons, countering specific threats and targets. The modern mine can now incorporate a level of artificial intelligence selecting its target within the parameters of its defensive role.

2.2 THE TASK

Defensive mine countermeasures or DMCM in the field are divided into active and passive categories. Active MCM is directed towards the removal and/or destruction of mines and typically includes activities such as mine-hunting, mine sweeping and clearance diving. Passive MCM alternatively involves measures such as controlling ship movements and instilling signature reduction systems into ships.

Mine hunting is a highly specialised operation, requiring purpose built vessels in conjunction with detection and disposal equipment. In surf zone regions it has often involved the use of divers, remotely operated vehicles (ROVs') or mine disposal vehicles (MDVs) to detect, classify and neutralize mines. Divers are also used to recover mines for subsequent exploitation and intelligence purposes. Secrecy and security are vital in the use of these amphibious operations.

The task of mine detection and neutralisation is a high risk one, fraught with complications and dangers. The need for effective reconnaissance of coastal and surf zone regions is paramount to the successful conduct of military operations. Forces must be able to move ashore within potentially hostile environments in a covert manner.

Remote mine reconnaissance and the mine-hunting operations are seen to be the key to the challenges of modern day mine warfare, particularly where amphibious operations are contemplated. Advances in modern technology now afford the mine hunter the option to use autonomous or remotely operated vehicles to search out the mine threat through a wide range of detection devices such as magnetic imaging, sonar and laser imaging.[2.2]

These vehicles can be successfully launched from a variety of surface platforms and submarines, allowing any force to operate in the area to maintain a low profile whilst ensuring that it is ready to provide an adequate response to any hostile forces it may meet. Autonomous and remotely operated vehicles have proved themselves in operations in the Gulf and in the former Yugoslavia. Trials aboard submarines have also shown that these vehicles can provide "over the horizon" surveillance and targeting data without disclosing a forces presence by or intentions.

2.3 THE FUTURE

In 1999 a study by the United States naval research advisory committee (NRAC), into the application of unmanned underwater vehicles (UUVs) in mine counter-measures, highlighted the desirable capabilities for such systems and were listed as:[(2.1)]

1) The ability to operate in very shallow water and surf zone regions.
2) Part of sufficient capability to support propulsion and combat systems (sensors, on-board computer, syndications, and neutralisation).
3) Robustness and durability to perform reliably in a hazardous environment.
4) Vehicle footprint size reduced to the degree that technology can allow, to facilitate handling and flexibility with respect to transportation and deployment.
5) Ease of launch and recovery.
6) Precise navigation which allows for a common tactical picture and provides for safe navigation, mine avoidance, and re-acquisition if necessary for neutralisation purposes.
7) Speed in conduct of mission, which applies not only to the speed at which MCM platforms can cover a threat area, but also to the speed of data exchange, processing and fusion of information.

8) Ability to bottom map, assess the environment, and fulfil the "detect-to-engage" sequence; i.e. detect, classify, and identify the (or provide a high degree of certainty) the presence of naval mines, successfully discriminating them from numerous and ever-present non-mine bottom objects (NOMBOs) [2.1]

Further conclusions of the committee underlined the increasingly important role in the MCM missions of the underwater vehicle and that "naval forces will therefore require a family of UUVs and sensor systems to provide an end to end capability over the broad littoral environment."

Finally the committee identified that "the most economical approach is to tailor the individual elements of the family of vehicles to the domain in which each has the best potential for effective operation." The study concluded that autonomous or remotely controlled low observable surface and underwater vehicles could effectively cover very shallow water and surf zone regions. "When clandestine operations are a requirement, the totally submersible unmanned underwater vehicle is the only solution."

The need for effective none acoustics sensors highlighted by the nature of modern very shallow water and surf zone deployed mines and the limitations of sonar systems in these regions, has increased research dramatically in recent years. This accompanied by the increased abundance of cheap signal processing and material fabrication techniques has made such systems more viable and significantly improved their performance. In comparison to sonar though, these systems achieve a reduced effective range. [2.2]

One particular direction in which research has been undertaken in recent years is towards that of underwater optical viewing. While the greatest problems of such systems has been that of limited range the distinct advantage they can offer is their ability to capture images of high resolution that are able to be interpreted in a more natural fashion. [2.3]

Development in this field has been greatly aided by the availability of increasingly cost efficient optical components and effective computer-based imaging systems. Added to this various techniques have been devised to improve the quality and range of underwater optical imaging. These will be discussed later.

To incorporate such a system on a mine counter-measures platform, certain criteria have to be met. Returned to the main points outline by the NRAC report, the priorities for such a system can be identified. In particular, points 6 to 8 of the text should be reviewed. Point 6 requires "precise navigation which allows for a common tactical picture and provides for safe navigation, mine avoidance, and re-acquisition if necessary for neutralisation purposes." In alternate terms, the system should be able to offer visibility in a manner though allow not only navigation but was also aid in the handling of any target object.

Point 7 "Speed in conduct of mission, which applies not only to the speed at which MCM platforms can cover a threat area, but also to the speed of data exchange, processing and fusion of information." This would require the ability to transfer target and environmental information quickly and efficiently to either the operator or other relevant systems incorporated in the vehicle.

Point 8 "The ability to bottom map, assess the environment, and fulfil; the; detect-to-engage sequence; i.e. detect, classify, and identify the (or provide a high degree of certainty) the presence of naval mines, successfully discriminating them from numerous and ever-present non-mine bottom objects (NOMBOs)." The system must be able to adequately visualise target objects to extend the allowances for true recognition.

In response to these requirements the Defence Evaluation and Research Agency (DERA), Bincleaves began development on a new generation of UUVs targeted at mine counter-measures within these challenging regions.

These vehicles would be required to be deployed from a vessel situated offshore and be able to navigate and operate effectively in shallow waters and the surf zone.

In the search for effective none acoustic based sensors, DERA looked to Cranfield University, Department of Marine Technology and in 1996 work began on the deployment of the Cranfield laser stripe imaging system on these vehicles. The first such vehicle was the NASP or Non-Acoustic Sensor Platform which incorporated the system in a hammerhead Configuration situated at the front of the vehicle (see figure 1.1). This was to be followed by the ESP or Enhanced Sensor Platform which would incorporate the imaging system with the use a magnetometer to identify potential target objects and is illustrated in figure1.2.

These vehicles are intended to move MCM into an autonomous age, navigating its own passage through the surf zone under the guidance of pre-programmed missions. Contact with the surface is purely though visual tracking by means of a fibre optic link allowing immediate warning to the surface of the presence and position of mine threats in the region.

3 ROV OVERVIEW

3.1 REMOTELY OPERATED VEHICLES (ROVs)

The origins of the Remotely Operated Vehicle or ROV can be traced to the development of the Programmed Underwater Vehicle or PUV, a torpedo developed by Luppis-Whitehead Automobile in Austria in 1864. True ROVs though, definition as "those controlled from the surface by means of a tether" were first developed by Dimitri Rebikoff in 1953 with a vehicle named POODLE. (3.1)

Early development by the United States Navy was directed towards the recovery of underwater ordnance lost during sea tests. In 1966 the ROVs potential was underlined when US Navy's Cable Controlled Underwater Recovery Vehicle system or CURV, recovered an atomic bomb lost off Palomares Spain. In 1973 two pilots of the manned submersible Pisces were rescued off Cork, Ireland from a depth of 485 metres. More recently in March 1995 the Japanese ROV Kaiko, developed by Mitsui and JAMSTEC reached the deepest point of the Marianas Trench, at some 10911 metres. (3.2)

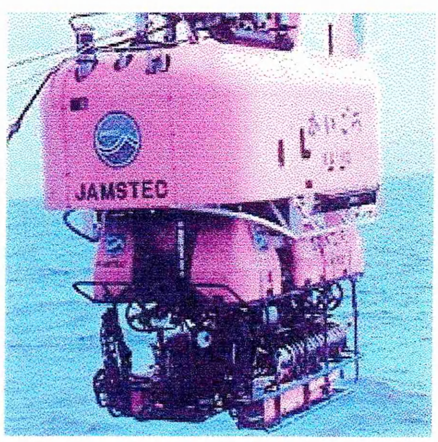


Figure 3.1: The JAMSTEC system used to reach 10911metres in the Marianas Trench. (3.2)

ROVs were first utilised for industrial purposes by the offshore oil and gas industry with the development of basic inspection vehicles. Since then their use has extended throughout subsea operations ranging from multi-form vehicles to highly dedicated single task models. ROVs have now become invaluable as oil exploration migrates into deeper and deeper waters, but their applications stretch far beyond this industry alone. The technology has reached a level of cost effectiveness that allows organizations from police departments to academic institutions to operate vehicles ranging from small inspection vehicles to deep ocean research systems.

3.2 UNTETHERED, AUTONOMOUS UNDERWATER VEHICLES (AUVs)

The next stage in the development of the ROV was the removal of the restraint of the umbilical, leading to the development of Autonomous Underwater Vehicles (AUVs). Early work began in the 1960s, with Dimitri Rebikoff's '*SEA SPOOK*', and the '*SPURV*' (Self-Propelled Underwater Research Vehicle) developed by the University of Washington's Applied Physics Laboratory. The development of these vehicles though was required to wait for advances in computer technology. Hampered by size, expense and inefficiency it is only in the last twenty years that the concept of using AUVs is beginning to become reality.

Today many different AUV projects are developing vehicles for various applications. The offshore oil and gas industry is looking at AUVs to lower the cost of operations in many areas. Japan is planning an AUV capable of reaching the deepest point of the Marianas Trench and critical breakthroughs are also coming out of academia at institutions such as Florida Atlantic University, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, where the high cost barriers of AUV development are being broken down. Possibly some of the most significant developments have been undertaken by the military, where overall investments have reached several hundred million dollars in the United States with the continued development of the Near-Term Mine Reconnaissance System (NMRS) and Long-Term Mine Reconnaissance System (LMRS). Launched from submarines, these AUVs are designed to allow mine detection capabilities in a relatively covert manner, without directly risking the lives of their personnel. [(3.1)]

3.3 MILITARY APPLICATIONS

As is often the case, it was for military applications that the technology for unmanned underwater vehicles was originally developed, targeting recovery and basic observation tasks. The technology has moved on sufficiently though to allow many other applications to be considered. In recent years an altering in the priorities of national governments and a refocusing on the needs of the military in a new world order has spurred the development of ROVs and AUVs for defensive applications. In fields that demand considerable development costs it is often the military that can provide sufficient funding for advancement, as the requirement for effective results tends to override those of cost efficiency.

MCM has become critical not only for surface ships, but also for submarines. If future battles are to be fought along world coastlines, with mobility a key factor, then safe operating areas needed to be found or established. In the US, major moves were made to solicit the development of "off board sensors" for use from submarines. The threat had changed and the NMRS, LMRS and other versions of shallower water systems began to achieve a foothold in the US Navy.

Prior to the end of the cold war the priority amongst NATO members was to exceed the technology of the Soviet Union all military fields. This was particularly true for the United States Military who attempted to lead the way in all areas of subsea search and recovery. New applications by the military for unmanned vehicles included the area of mine countermeasures, where tethered ROVs were much more expendable than a ship or a diver. In addition, there were many programs conducting research into recovery technology and the fledgling arena of untethered vehicles used for search.

Since then the technology developed behind the "Iron Curtain" has come into the open and are demonstrated by amongst others, the '*MT 88'* autonomous vehicle, developed by the institute of Marine Technology Problems in Vladivostok.

European development did not take off until the 1980s and tended to be based on technology from the United States. Primary applications centred on support of the North Sea oil and gas industry but the technology was applied to European projects for mine counter measures developing vehicles such as the 'Pinguin', 'Pluto' and 'PAP'. Some attempts were made to match the technology of the United States and the Soviet Union, by developing systems for deeper applications but proved largely unsuccessful leaving the priorities based in Mine Counter Measures (MCM).

The potential for ROV applications in certain areas has been reached and the requirements of the technology are towards AUVs. The ability to free the vehicle from the limitations of its umbilical would allow the development of true robots, capable of carrying out pre-designated tasks without the requirement of surface operator intervention. AUVs are being used to carry out high precision seabed surveys and long-distance fibre optic cable laying amongst other autonomous tasks. [3.3]

The near future will see developments in AUV technology towards five major applications:

- Seabed surveys.
- Oceanographic data gathering.
- Pipeline touchdown monitoring.
- Floating production systems support operations.
- military applications in particular, mine counter measures (MCM).

The drive for commercial development will be led by the oil and gas industry with a projected cost savings, estimated by Shell International of $30 million increasing to $75 million within five years. Fugro Geoservices have further estimated that a reduction in deep-water survey time can be achieved of up to 50 %. [3.3]. "The future will undoubtedly see vast networks of "inner space satellites" that autonomously roam the ocean gathering data in a wide variety of applications". [3.1]

The future thrust in the military will be toward autonomous vehicles that are not only capable, but low in cost. The technology under development in academia, and being fielded in the offshore oil fields, will soon find its way into military systems of the future, whether for intelligence collection, search, reconnaissance, mine countermeasures or various other applications ROVs and AUVs will both find a major role in the military.

What ever the requirements of these systems holds in the future, the ability to visualise the environment in which they operate is vital. Optical imaging by means of video, electronic still or film cameras is a highly useful tool in oceanographic and forensic subsea operations. The technical difficulties encountered in underwater optical imaging are great in comparison to those faced in the land, air and space Imaging. In water the greatest obstacle is that of rapid light attenuation and back scatter. [3.4]

4 FACTORS AFFECTING UNDERWATER IMAGING

It was mentioned that limitations of underwater optical imaging systems revolve primarily around the effective range. This is a problem that has faced those who have attempted to capture the underwater environment on film since its origins in the last century. The range is restricted by the attenuation of light as it travels through the water column. Although light attenuates in air, its attenuation in water is quoted as being 1000 times greater.[(4.1)] But water is not a standard medium and its effects on light vary dramatically from pure distilled water up to highly turbid coastal and estuarine samples.

In the clearest ocean water, targets can be clearly image, but the range can be limited to between 5 and 10 metres. In areas where the turbidity is greatly increased such as coastal and surf zone regions, this range can be reduced to less than a metre. It is important then to form a basic understanding of how light behaves in water and the conditions that are experienced in the medium that will affect its behaviour. The optical properties of water are divided into two categories these are the inherent optical properties of water and the apparent optical properties of water.

The apparent optical properties of water are those measures of light penetration in the water that are dependent on the sunlight and the inherent optical properties of water. As such these properties are highly dependent on the time of day and the strength of the sun. It is inherent optical properties of water though, that are of particular relevance in the use of underwater optical imaging systems where artificial illumination sources are used.

4.1 INHERENT OPTICAL PROPERTIES OF WATER (IOPs)

The Inherent optical properties (IOP) of seawater are those characteristics that are not dependent upon the underwater light field, or in different terms they are not influenced by outside sources. IOPs can be measured in the laboratory, at night or at depths too great for light to reach. The difficulties faced in the visualisation of objects in the underwater environment are primarily due to these properties so a basic appreciation is important.

IOPs are defined by four coefficients, those of;

1) Attenuation.
2) Absorption.
3) Scattering.
4) The volume scattering function.

4.2 ATTENUATION OF LIGHT IN THE WATER COLUMN

The propagation of light in water in any direction is attenuated as a result of two properties; absorption and scattering and can occur in even the purest of water. Absorption results in the progressive removal of light were as scattering results in the redirection of light with no resultant conversion of energy, thus leading to an increased probability of absorption along its path.

4.2.1 LIGHT ABSORPTION IN WATER

The absorption of light is the mechanism by which the photons are converted into different forms of energy. In the case of water the conversion is generally into thermal energy. The amount of absorption varies with the wavelength of incident light. Absorption in pure water varies dramatically over the visible spectrum, from its highest within the infra-red wavelengths to its lowest in the blue-green range. The absorption properties of sea water can be described by the combined absorption coefficients of five components:

1) Water.
2) Suspended particles.
3) Phytoplankton.
4) Detritus.
5) Dissolved substances.

If "**a**" represents absorption, the total light absorption properties of the sea water can thus be described simply as:

$$a_{\text{total}} = a_{\text{water}} + a_{\text{particles}} + a_{\text{phytoplankton}} + a_{\text{detritus}} + a_{\text{dissolved substances}}$$

Equation 4.1

Each of these components holds its own distinct absorption spectrum. Therefore the penetration of light through water is dependent upon the level and nature of the materials held in suspension in the water column. Variations in any one of these components can lead to changes in the absorption properties of the water column. If the change is large enough, the colour of the water will change.

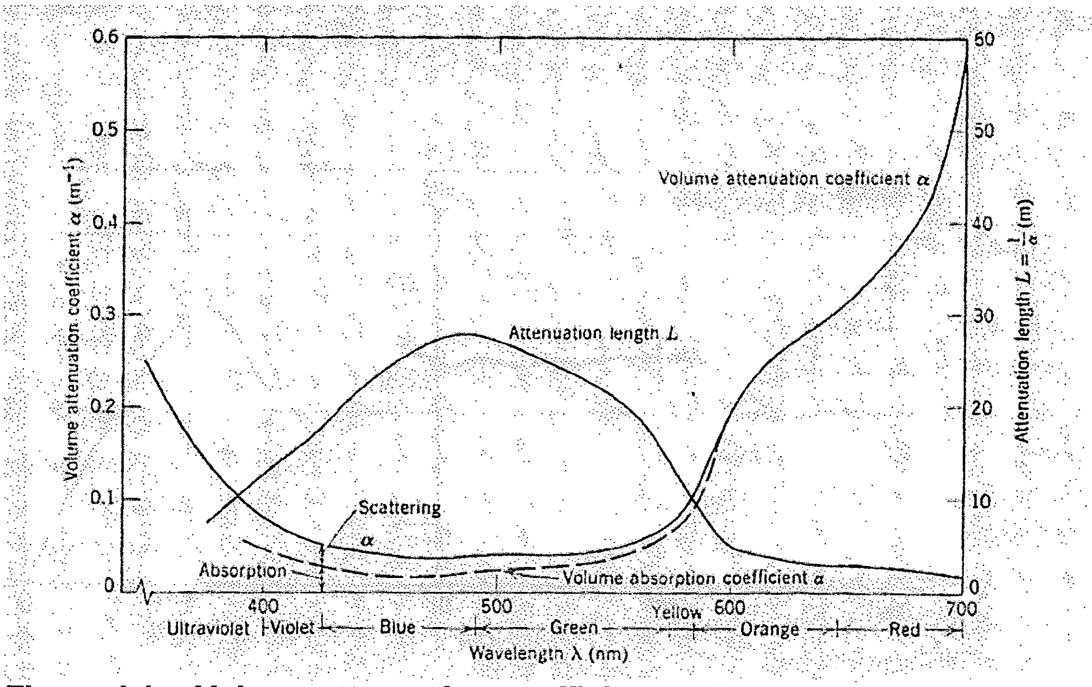


Figure 4.1: Volume attenuation coefficient and attenuation length in the visible spectrum for distilled water. (4.1)

It can be seen from the graph above, absorption is at its strongest in the infra-red region nm and absorbs the least in the blue, green region. In pure water the absorption of light in the red light is 177 times stronger than absorption of blue light. (4.2)

4.2.2 LIGHT SCATTERING IN WATER

During scattering events light undergoes a change in direction. This may occur due to collisions with molecules of the matter, or with particles present in the matter. As such there is a significant variance in the size of the particles at which collisions will occur, resulting in a difference in the nature of the scattering.

As light comes in contact with water particles, scattering occurs as a result of diffraction, refraction and reflection and will scatter light in all directions, though most scattering occurs in the forward direction. Backscatter will result in a reduction of light propagating on its original path through the water column, but increases the apparent brightness to an observer. Thus leaving the observer with a loss of clarity and detail, when attempting to visualise target objects in the water. Figure 4.2 illustrates the processes by which particles can scatter light.

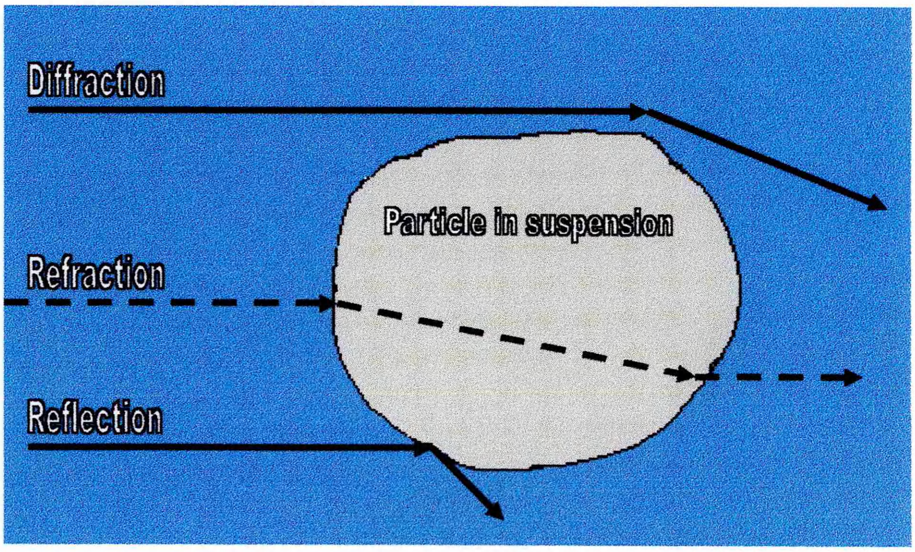


Figure 4.2: Light scattering events in water

The processes of reflection and refraction occur at the interface of two different media, such as at the surface of the water, or at the surface of a particle. Larger particles held in suspension in the water will show highly variant reflective qualities dependant upon their nature. Irregular surfaces on these particles will result in photons reflecting off their surface in a wide range of directions depicted in figure 4.3 below.

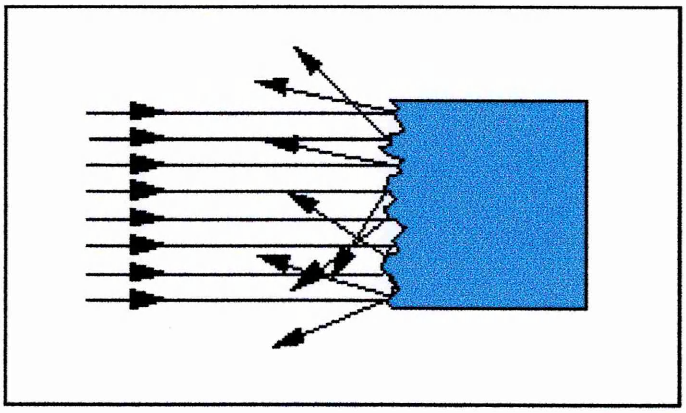


Figure 4.3: Photon reflection on larger particles with irregular surfaces.

Refraction is the result of a change in the velocity of light, which occurs when light enters a new medium. Light travels faster through air than through water, glass or a particle. As a result of the change in speed, the direction of travel will change, as can be seen in figure 4.2. The light changes direction whenever there is a change of medium, both when it enters the particle and when in leaves the particle.

Diffraction is a change in the direction of the light, due to the proximity of the particle. As a beam of light approaches a particle, the effect of the particle on water causes the light to change directions. Diffraction affects as much light as a large particle itself absorbs and scatters, doubling the amount of attenuated light by one particle. [4.3]

Scattering events will also result in further absorption. Changing directions increases the path length of the light, thereby increasing its probability of being absorbed. The total amount of light loss depends upon the length of the water column and the coefficients of absorption and scattering.

Scattering events fall into one of two categories; 'Rayleigh' scattering and 'Mie' scattering:

4.2.2.1 Raleigh Scattering

Rayleigh scattering occurs at particles and molecules that are small in respect to the wavelength of the light and will increase for shorter wavelengths i.e. blue. The nature of the scattering that occurs at this level is a general symmetrical pattern, and is shown in figure 4.4.

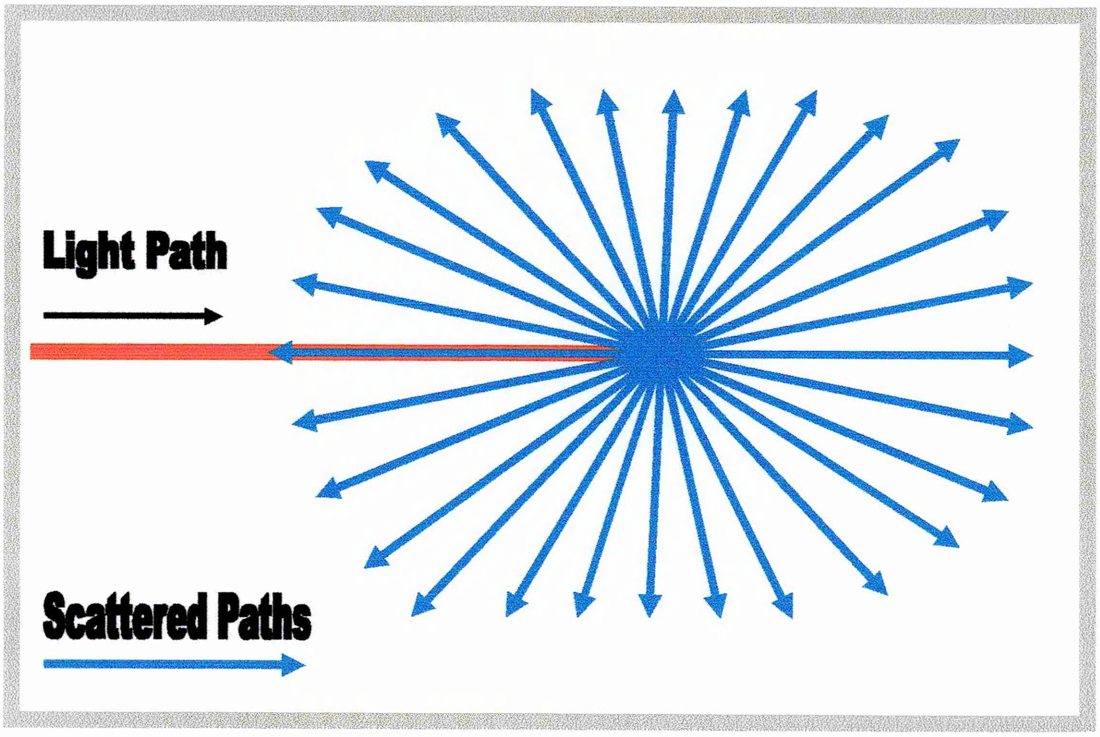


Figure 4.4: Rayleigh scattering. Results in a symmetrical distribution of scattered light.

4.2.2.2 Mie Scattering

Mie scattering alternatively occurs at particles that are larger than the wavelength of the incident light. Particles such as these are formed from suspended organic or inorganic substances. The degree to which these substances scatter light as it passes through the water column can be expressed in terms of turbidity. Mie scattering results in scattering that is greater in the direction of the incident light and can be seen graphically in figure 4.5.

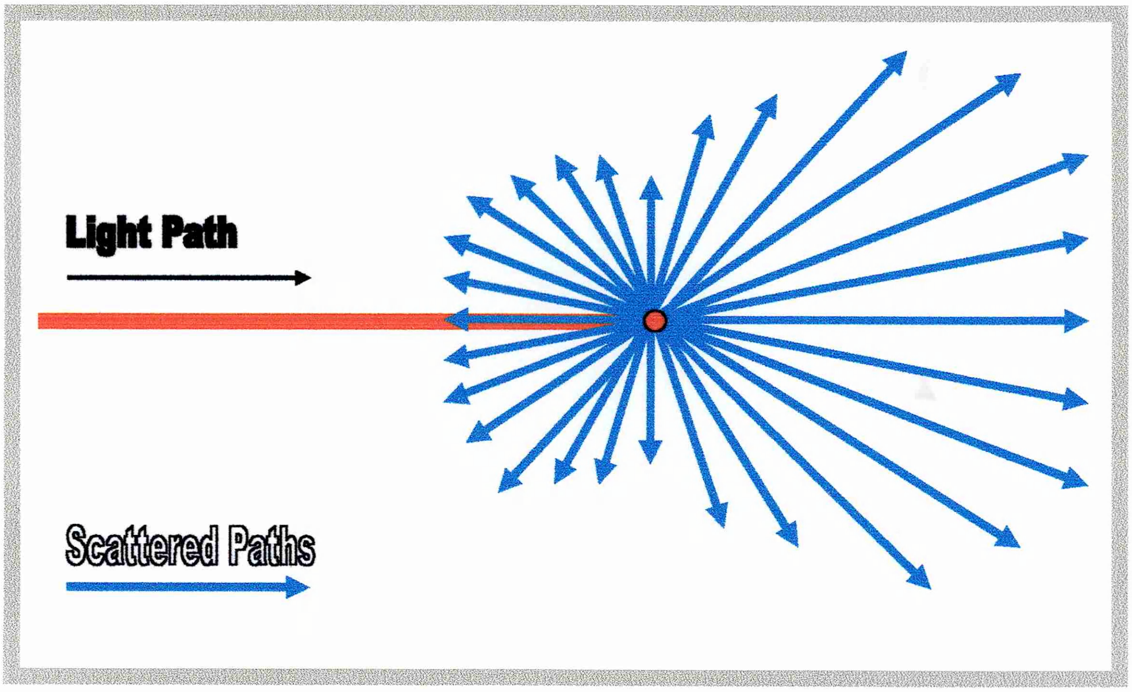


Figure 4.5: Mie scattering on collision with smaller particles

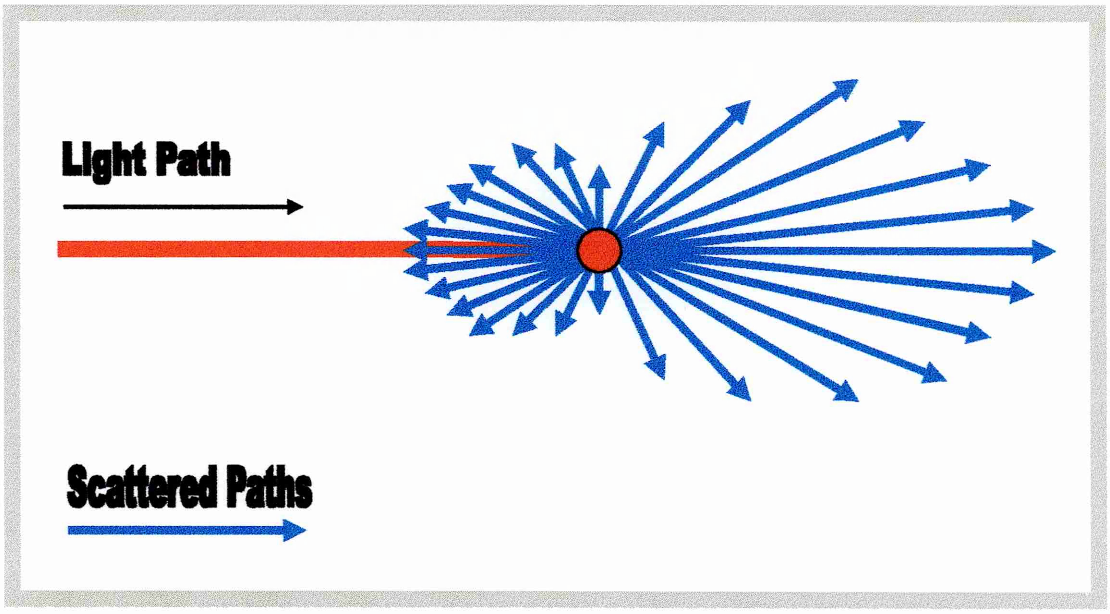


Figure 4.6: Mie scattering on collision with larger particles

Attenuation of light in seawater thus can be described as the combined absorption and scattering effects of water molecules, suspended particles, phytoplankton, Detritus and dissolved substances. Table 4.1

Component	Absorption	Scattering	
		Dominant scattering event	Angular scattering function
Water molecules	Highly dependent on wavelength. Least in blue. Highest in red	Rayleigh	Symmetrical
Suspended particles	Varies by nature of particle	Mie	Forward dominant
Phytoplankton	Varies by nature of particle	Mie	Forward dominant
Detritus	Negligible compared with other components	Mie	Forward dominant
Dissolved substances	Negligible compared with other components	Mie	Forward dominant

Table 4.1: Summary of sources of attenuations in water

From the summary it is seen that in seawater showing high levels of suspended inorganic and organic substances and dissolved substances results in a dominance of forward scattering events. An aspect that has significant repercussions on the effectiveness of underwater viewing systems.

4.2.3 VOLUME SCATTERING FUNCTION

The angular distribution of scattered light with respect to the incident beam of light is defined in terms of the volume scattering function. The function may be thought of as the probability of light being scattered in a particular direction relative to its initial direction. .It was noted that Rayleigh scattering events for example on water molecules will generally scatter light in a symmetrical fashion, so that the volume scattering function is virtually equal in all directions. Particulate matter, though shows mie scattering characteristics, and thus scatters most of its impinging light in the forward direction.

The volume scattering function for a body of water can be shown in terms of a polar plot. Figure 4.7 below, shows a comparison of oceanic waters against pure water. Increased scattering events are shown in both the oceanic samples increasing by a factor of 2 in regions over 90° from the direction of incident light. It is the raised level of forward scattering events though that is particularly significant. At regions of 10° from the direction of the incident light, forward scattering has increased by a factor of 500. [4.1]

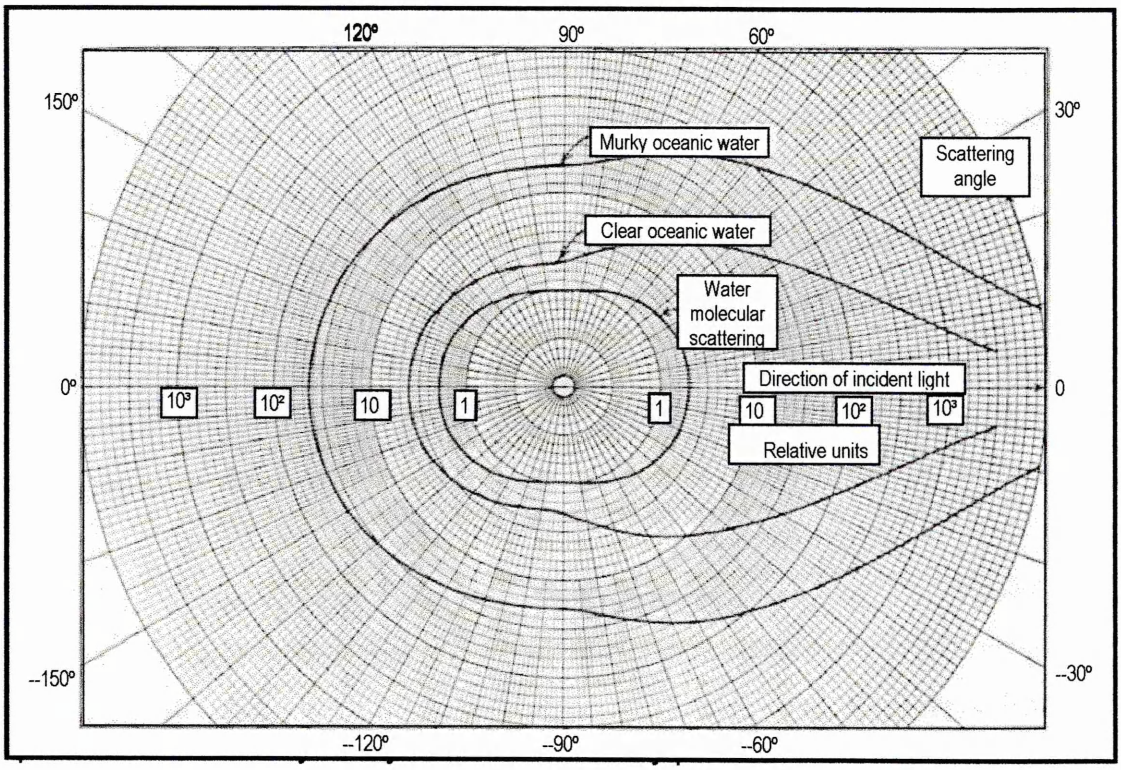


Figure 4.8: Properties vary extensively depending upon the type and location of the water body. (4.1)

Estuary or coastal ecosystem are particularly dynamic regions and are exposed to more human activity than the deep ocean. They are shallow compared to an ocean and receive both fresh and marine water. These physical and chemical differences cause the optical properties to be distinct. The distinct optical properties cause light to behave differently in each water body, leading to different colours and clarity in each water body type.

The attenuation of light as it passes through water means better than illumination source will have a finite range. It is useful to be able to describe a body of water in terms of the level of attenuation that will occur for illumination source. This can be expressed in terms of the transmissivity of the water of or alpha (α).

For a collimated monochromatic beam travelling through a body of water containing particles, light attenuation is either by absorption, or scattering outside of the collimated beam. The amount of light loss depends upon the range and the coefficients of absorption and scattering. These coefficients have units of m^{-1} and are independent of the range; however, the total light loss is dependent upon the length of the range, so it is always related to the path length. Thus the volume attenuation coefficient, Alpha (α) can be expressed as a sum of the absorption and scattering coefficients.

The term attenuation length is the reciprocal of Alpha and is also used in reference to transmissivity. Measured in units of metres (m), attenuation length can provide a useful means of estimating and imaging systems operational range. Thus the performance of underwater imaging systems can be expressed in terms of the number of the attenuation lengths the system can operate.

The attenuation of a monochromatic beam can be expressed by the exponential relationship::

$$I(1) = I_o e^{-\alpha 1}$$

Where: **I(1)** = The intensity at a distance 1 from the reference point (I_o).

α = The volume attenuation coefficient.

Very deep, clear ocean waters are represented by values for Alpha of less than $0.1m^{-1}$. Alpha values of between $0.5m^{-1}$ and $1m^{-1}$ are typical of near coastal waters, whilst values greater than $1m^{-1}$ are frequently found in harbours and bays. Measurements of Alpha have been taken of up to $3m^{-1}$ in localised offshore areas the conditions of heavy rain that has increased run-off from land and increased turbidity. [4.4]

5 UNDERWATER VIEWING

The adage "If it wasn't for the water, underwater photography would be easy" still stands today. But it is probably the difficulties of light attenuation and in particular the effects of back scatter that have raised more problems in the history of underwater viewing than any other. The effects of back scatter on underwater images range from small white specks across the picture to completely obscuring any image taken in the region. Whatever the level of back scatter though the effect will be to detract from the cleanliness of the image and to distract the eye of the observer from the subject in the frame.

The requirements for clean, recognisable images have extended beyond the artistic and the 'hobbyists' attempting to capture a different realm in photographic form. Today its requirements extend throughout the marine and subsea industries and into scientific research and a defence sector. It is developments within these fields that have driven the science of underwater imaging forward in recent years.

5.1 A BRIEF HISTORY OF UNDERWATER CAMERAS

Photography was first used to capture the underwater environment in February 1856, by William Thompson, but it is Frenchman, Louis Boutan who is credited as the true pioneer of underwater photography [(5.1)] 1893 his images taken in the bay Banyuls-on-the-sea showed the possibilities for underwater photography. Early pioneers like Thompson and Boutan, struggled with adequate camera housings to withstand the pressures encountered at depth and with sufficient illumination to achieve their images. With illumination periods of up to 30 minutes often required, effective images of a constantly changing environment were difficult to capture. It is Boutan who is also credited with the identification of the backscattering of light as it passes through water. [(5.1)]

Figure 5.1: Louis Boutan, circa 1900
www.vdst-visuelle-medien.de (5.2)

It was another Frenchman, Etienne Peau who furthered the science, publishing his images in his illustrated ocean biology reports. Between 1908 and 1913 Englishman, Francis Ward succeeded in photographing, in colour; pikes, otters, frogs and diving water-birds. In 1915 the first underwater moving images were captured by American John Ernest Williamson showing him killing a shark with a knife. (5.1)

Underwater photography began to make significant strides with the invention of the first diving apparatus by the Frenchman Yves le Prieur, allowing photographers to remain submerged for longer periods and thus improving the quality of the final images. In the late 1930s Austrian, Hans Hass explored the optical and physical conditions that effected the capturing of images underwater. In 1949 Hass was able to develop, in co-operation with the German company Franke & Heidecke, the Rolleimarin; an underwater housing for the 2-optic Rolleiflex 6 x 6, and it was the Rolleimarin was considered the ultimate in underwater housing right up until the early 1970s. (5.1)

Probably the most famous of the underwater photographic pioneers was the Frenchman Jaques Yves Cousteau who in 1957, with Jean de Wouters developed the first waterproof 35mm camera, the Calypso Phot. This camera later developed into the Nikonos viewfinder camera after the Nikon company acquired the license in the early 1960s. [5.1]

The use of underwater optical imaging systems today is highly dependant upon the application, with various techniques being employed to achieve the best results. Viewing over longer distances often relies upon low light cameras. Colour images provide a level of contrast, but illumination must be increased resulting in increased backscatter. In close proximity to a target object though, this method can be effective. Any system then must be matched to its required tasks, as greater diversity will mean larger and more cumbersome delivery systems.

5.2 THE USE OF UNDERWATER CAMERAS TODAY

In the use of ROVs/AUVs, the ability to visualise the region around the vehicle is vital. But this is not only for purposes of navigation but also to assist in the tasks that the vehicle is required to perform. Cameras experience problems similar to human vision, a lack of sensitivity at low light levels. Dependent upon the requirements of the vehicle, ROVs are capable of carrying up to 10 cameras whilst operating five or more of these cameras at any one time. The images can then be transferred to the mother vessel through fibre-optic cable carried either within an umbilical or as a free connection.

Closed circuit television/video systems are able to provide real-time images to the operator; this is a necessity for the controller of the system when navigating. These images though often have low resolution. Various camera systems have become available for use in the underwater environment; these include Silicon Intensified Target or SIT cameras, Silicon Diode Array (SDA) and Charge Coupled Device (CCD) cameras. Low Light Level or LLL cameras are capable of operating at levels of illumination many times lower than conventional tube cameras. It is SIT cameras though that are in most common use when imaging underwater.

5.3 LIGHTING

Early underwater photography was reliant purely upon ambient light, but with the development of magnesium flashes by Chaff our in 1893 a level of non-ambient light was afforded to the photographer. Some attempts were made towards an electrical lighting system by Ernest Bazin in 1872 but little evidence remains of the results. [(5.3)]

In 1947 Frenchmen, Dmitri Rebikoff succeeded in the development of the first underwater electronic flash system, the Rebikoff torpedo. The flash unit was large and cumbersome but was capable of superb results and allowed Rebikoff to produce renowned colour exposures of the underwater caves in the French Riviera. In the 1950s the sports of scuba diving and snorkelling began to emerge and it was with this that large-scale production of underwater illumination systems began. [(5.4)]

5.4 UNDERWATER VIEWING SYSTEMS

In comparison to sonar technology, optical imaging underwater has the advantage of offering high geometric resolution due to the short wavelengths of visible light. In contrast though is its limited penetration depth as a function of the optical attenuation coefficient is a distinct disadvantage. In the blue-green spectral range this can vary around 0.1 m^{-1} and up to 4 m^{-1} in highly turbid coastal waters. [(5.5)]

The problem of light attenuation due to absorption between the light source and a target is dependent upon range. Standing alone this would be a problem purely reliant upon the power of illumination system available or "power limited". .Unfortunately this is not the case in water.

The use of artificial illumination systems has become standard in underwater viewing, but the problems of back scatter are greatly increased with such systems. This is a phenomena close that of driving in dense fog. Two particular problems are experienced when viewing through a medium with suspended particles.

Firstly, light from illumination source propagates across the area between the viewer and a target object, but in doing so will illuminate the suspended particles, resulting in light scattering back to the observer. This means that a level of light returning to the observer is unwanted and the image contrast is being reduced. Added to this the amount of light available to illuminate the target object is reduced. The effect of this back scatter is to give a bright for-ground. In reality this is the volume of water that is shared between the beam of the illumination source and the field of view of the of observer or detection device and is described as the "back scatter volume".

Therefore the illumination required at the target object in order to provide a given contrast between target object and foreground, is increased as a function of the back scatter, while the actual light available at the object is reduced by the same mechanism. (5.6)

Secondly as light traverses the gap between the target object and the observer the effects of forward scatter are also experienced. This will further reduce contrast and cause the image detailed to appear blurred.

If we consider the use of black-and-white target for the monochromatic light source, if no scattering events are experienced the black regions of the target would not return any incident light to the detector $I_{min} = 0$, whilst the white regions would reflect all the incident light $I_{max} = 1$ Thus the contrast or modulation can be defined as;

$$MODULATION = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

This defines the ideal result to be 1. With the introduction of a scattering medium the contrast of the image will be reduced due to absorption and scattering. Therefore the modulation of the black region will increase from its ideal 0 and a white region will decrease from its ideal 1. Ultimately as range or scattering events increase the contrast will progressively move towards zero.

If the target object is moved further away the back scatter volume will increase thus the level of unwanted light or noise on the image will increase. Eventually the signal to noise ratio will result in the loss of use for imaging of a target object, a situation that is described as "contrast limiting". Returning to the analogy of driving in fog, the effective of increasing the power of illumination i.e. switching your lights to full beam, will not be to improve the situation but often make the situation worse.

The problem is then to remove as much of the unwanted noise from the image as possible. As range increases the back scatter volume will also increase, so to improve the quality of an image it will follow that the back scatter volume should be kept to a minimum. [5.7]

5.5 UNDERWATER IMAGING TECHNIQUES

Underwater vision systems can be categorised into passive and active systems. Passive systems operate under natural illumination and so is depth limited, whilst active systems make use of artificial illumination sources. Conventional active systems utilise an underwater camera with a field of view of between 50° and 60°. This is used with an illumination source such as an arc lamp which can have a beam range of over 90°. The attraction of these systems is its simplicity but there effectiveness is generally limited to imaging in relatively clear water as in conditions of high turbidity, the noise to image ratio can be too great. Active systems then require the suppression of the incidental illumination created by a scattering medium.

Several techniques have been developed to increase the range and quality of active underwater viewing systems by reducing backscatter, these include;

- Horizontal camera to light separation.
- Light behind Camera (LIBEC).[5.11]
- Illumination by scattered light.
- Light polarization.
- Monochromatic light sources.
- Laser based imaging techniques.
- Computer based image processing

5.5.1 HORIZONTAL CAMERA TO LIGHT SEPARATION

Basic underwater imaging systems rely upon the use of a camera and a standard illumination source, for example an arc lamp. The difficulties encountered by back scatter are greatly increased when the illumination source is positioned in close proximity to detector. Such an arrangement results in the maximising of the back scatter volume. By increasing the separation between the light source and the receiving camera, the volume of water common to both the illumination cone and the field of view of the camera can be reduced, effectively increasing the range of the system.

The closer the back scatter occurs to the camera, the brighter it appears on the image, as the back scattering medium is also closer to the illumination source. This further increases the detrimental effects on the image. By increasing the separation of the light source and the camera, this near field back scatter can be reduced. This relationship is shown in figure 5.2 below. It should also be noted that light reflecting off any point that it illuminates is subject to spreading.

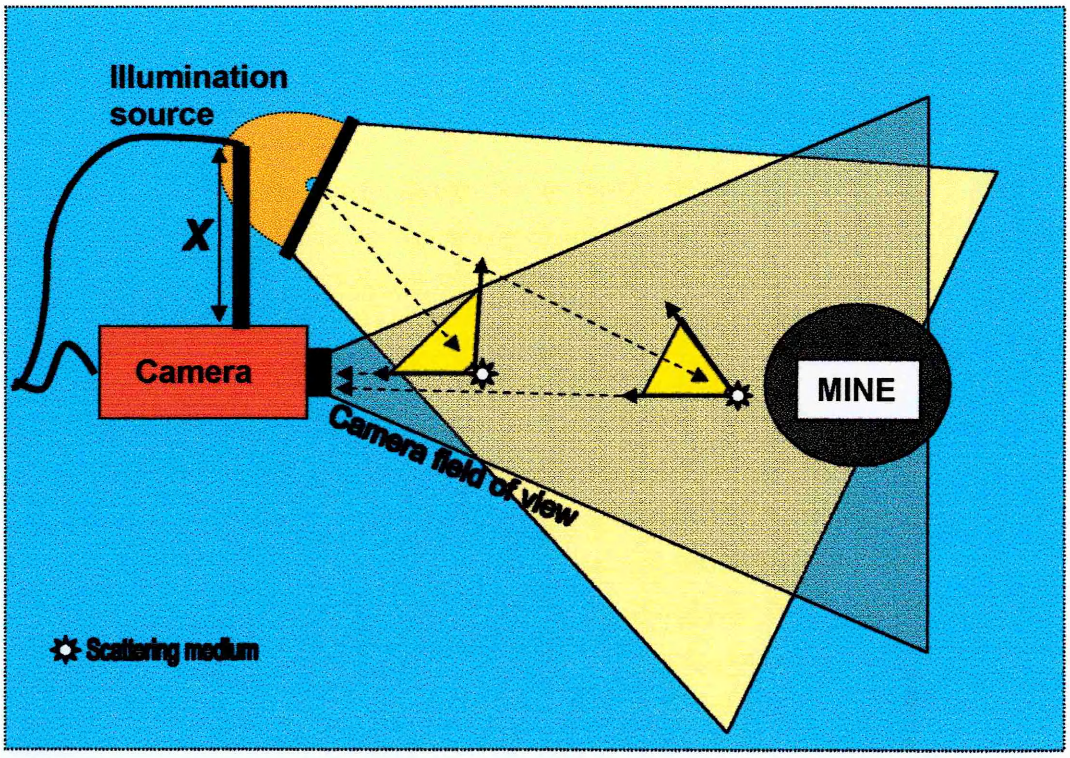


Figure 5.2: Effects of near field backscattering

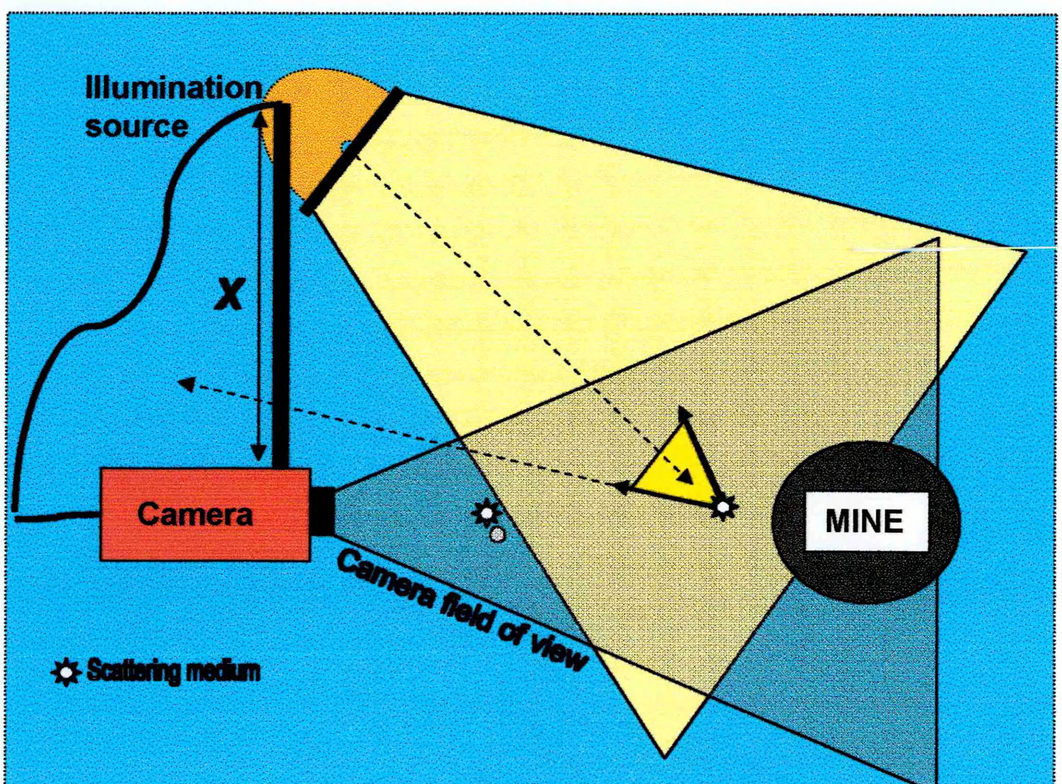


Figure 5.3: Backscatter can be minimized by increasing the separation distance *x*, between the Camera and illumination source.

By increased separation of light and camera illustrated in figure 5.3, spreading glare on the image can be reduced. This arrangement can also allow the image to show texture and a level of three-dimensionality through the presence of shading. Side lighting can provide a more visually interesting image than those achieved through flat, frontal lighting.

If a light source is used that provides a more directional beam of light, the risk of illuminating particles out with the main beam is reduced and so can further lesson scatter. More directionality can be achieved by the use of directional shutters or a "snoot" placed on the lamp. [(5.8)]

5.5.2 LIGHT BEHIND CAMERA (LIBEC)

In the early 1970s the United States Naval Research Laboratory (NRL), developed a deep sea photographic system known as light behind the camera or LIBEC (Light Behind Camera).The use of wide angle lenses allowed a camera to achieve a wider field of view, this though will deteriorate the image that is received as the common volume of water shared between the light beam and the camera field of view is increased. [(5.9)]

By positioning the illumination source behind the camera, the illumination cone spreads out before it reaches the target object, this primarily reduces the common volume but also reduces the intensity of the light experienced at back scattering "hotspots", and has the added advantage of that the illumination source were not appear in the corners of wide-angle images. It is noted in Huggett (1990) that this orientation of light and camera is the most effective for increasing range (up to 21 metres) [(5.10)]

On the 10^{th} of April 1963 the United States nuclear submarine thresher sank in the North Atlantic. Some years later, LIBEC was used by the NRL to visualise the wreck onboard the U.S.N.S. Mizar. LIBEC suspended high-intensity electronic flash lamps well above the ocean bottom, making it possible to shoot 120-foot-wide sections of the seafloor. (5.11)

5.5.3 ILLUMINATION BY SCATTERING LIGHT

The effects of visualising through a scattering medium can be used to an advantage if the scattering events themselves can be used to illuminate the target object. With the use of a high powered, directed beam from the spot light the illumination can be directed close to but not within the camera field of view. The target can then be illuminated by means of the scattered light from the beam. This can greatly reduce the effects of back scatter but is highly reliant upon the power of the illumination source and the level of turbidity.

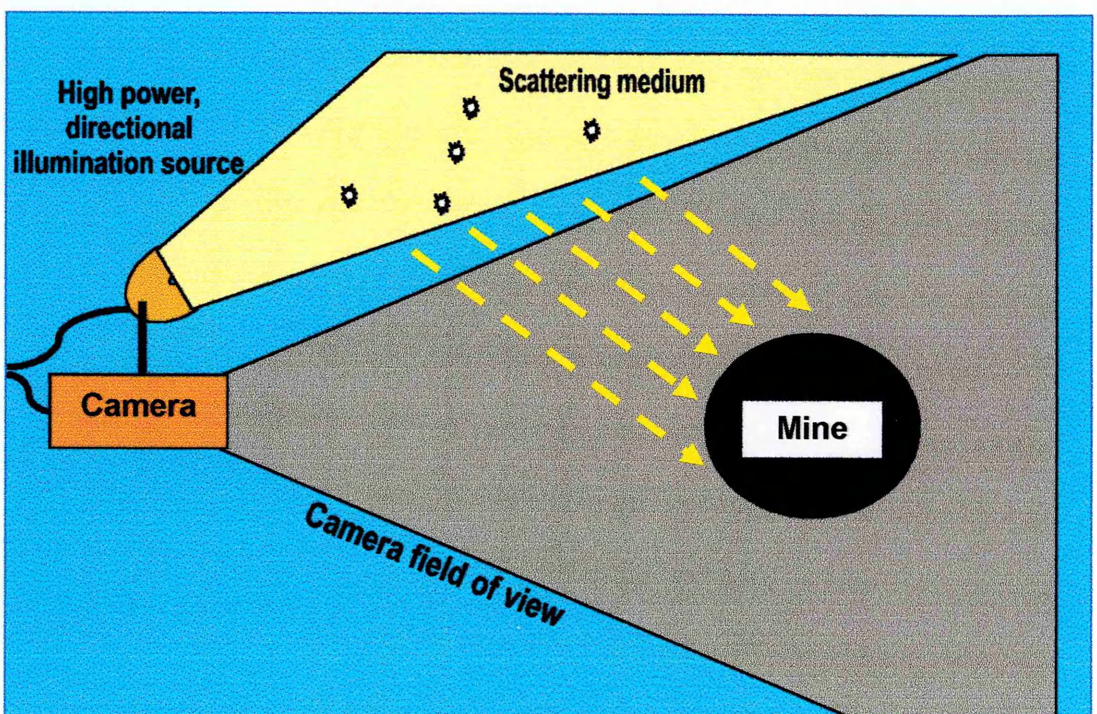


Figure 5.4: Scattering light used to illuminate target object in the water column

5.5.4 LIGHT POLARISATION

By illuminating the target with a polarized light source and using a cross polarized filter on the camera receiving the image, much of the target can be imaged whilst backscatter can be reduced considerably and contrast improved. This is possible as much of the backscattered light will retain its polarization whilst light reflected off the target object will be randomized. Circular polarization techniques work in much the same fashion. Light polarized at source in this fashion changes polarity on reflection. Suspended particles are small and thus single reflections take place on the surface and so light reflected on these objects are of an opposite polarization to the light source. A diffuse target object will create multiple reflections resulting in equal amounts of polarized and depolarized light. When the camera is fitted with the same polarization filter as the source, backscatter is greatly reduced as it is oppositely polarized.

Circular polarization holds an advantage over linear as it does not require accurate alignment of the filters. This technique also shows considerable visibility improvements over linear polarization. Polarisation filtering though does result in a loss of light reducing its effectiveness with increased range. **(5.11)**

5.5.5 MONOCHROMATIC LIGHT SOURCES

Due to the unsuitability of much of the visible spectrum for underwater illumination over distance, much of the back scatter can be reduced if optimum wavelengths are used. Monochromatic light can be produced in three different ways;

- by use of Filters,
- by use of Arc Lamps',
- by the use of Lasers.

5.5.5.1 Filter use

By using a filter that imitates the attenuation characteristics of the distance between camera and target, this technique can be used to its optimum potential. Filtering though reduces the total level of light making the system power limited. This can be overcome by the use of a more powerful light sources light sources. Filter use allows a system to be adapted to suit the conditions met in the environment and the range requirements of the imaging. [5.10]

5.5.5.2 Arc Lamp use

The most efficient arc lamp for the purpose of underwater illumination is the thallium lamp, which produce peak outputs in the desired blue green waveband The difficulties of using this illumination source is its power requirements. The lamp must be continuously in use and so requires a more reliable power supply than batteries [5.12]

5.5.5.3 Laser based imaging techniques

Active imaging techniques use lasers to enhance the visibility of objects that would otherwise be impossible to see. In sea water, blue/green show considerably less attenuation remaining visible over greater distances. For example, at a range of 20 meters, 44% of the light from a 532 nm green laser would remain as compared to .002% from an equivalent power 640nm RED laser. There are two basic methods of underwater imaging that incorporate lasers these are Range gating and synchronous line scanning systems. [5.13]

5.5.5.4 Range gating

Gated viewing systems are possibly one of the better known techniques developed to improve underwater viewing. By directing a pulse of the light towards a target object, that region between the viewing system and target that is affected by back scatter, can be removed from the final image by means of gating the returning light. If the range to the target object is known, then the time that the light takes to travel to the object can be calculated. The receiver or camera can then be momentarily switched off, allowing incidental illumination points to be ignored. The camera can then be switched on briefly to allow only useful information to be received by the camera. This process is shown in figure 5.5 below.

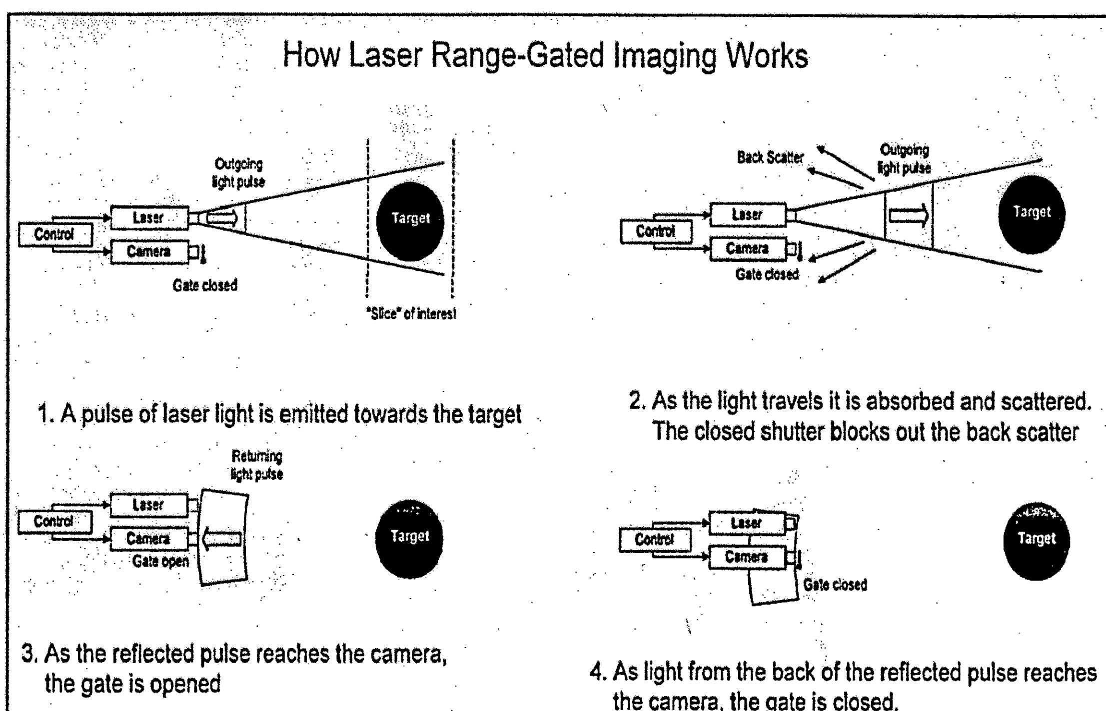


Figure 5.5: The range gating technique

Many systems use a laser light source which can illuminate a target in a point by point fashion. At each point in the angular scan, the laser is pulsed on for a very short time compared to the round trip propagation time for the light travelling to the target. Pulses of between 1 and 5 nanoseconds achieve best results in water. When the reflected light is received the electronically controlled shutter is opened for a time that corresponds to the depth of view. The image is formed from the light that returns with backscatter largely removed [5.14].

5.5.5.5 Synchronous Volume scanning

A synchronous volume scanning system uses a continuous wave laser intersecting at the target with a narrow instantaneous field-of-view (IFOV) detector. This creates an area of overlap which is scanned across the target to produce an image through the camera. This means there is a very small area of common volume or back scatter volume, so greatly reducing the effects of backscatter. Attenuation lengths of 4-6 can be achieved through this method. [5.15]

5.5.5.6 Laser line scanning

Using the synchronous scanning technique the laser beam can be used to illuminate a discrete region on a target object and the reflected light can be collected by a detector. The beam can be linearly scanned over the target and as the line is moved over the target each collected stripe can be used to progressively build an image of that target. The resolution of this image is dependent upon the beam quality of the laser used but such systems can produce high resolution images over a wide area in a relatively short time. The major limitation of this system have proved be the backscattering of the laser light and efforts to over come this problem have largely been targeted at the separation between laser and detector. Such techniques reduce the effect of backscatter dramatically as the scattering efficiency reduces dramatically when viewed off axis [5.16]. This technique is depicted in figure 5.6 below. The back scatter volume shown as the region within **A.B.** and **C** is reduced considerably by the use of the narrow beam of illumination to scan the target object.

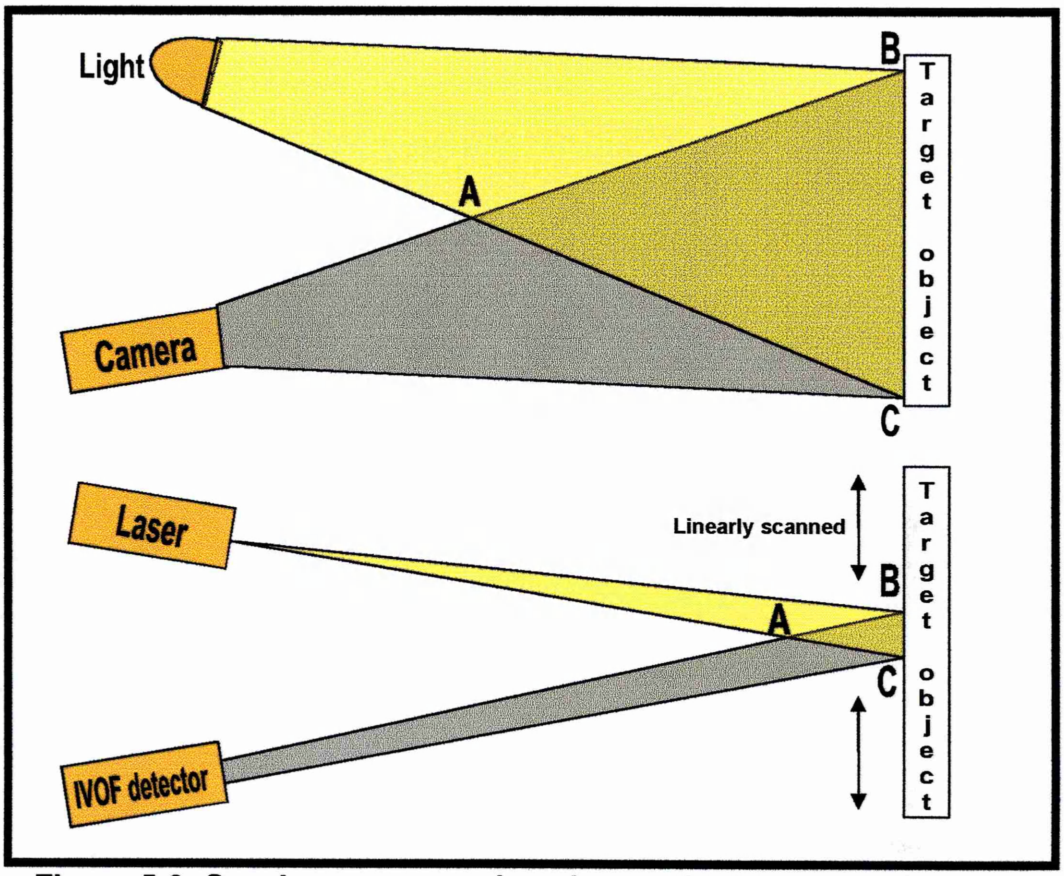


Figure 5.6: Synchronous scan imaging method, showing a greatly reduced back scatter volume within the region ABC.

5.5.6 COMPUTER BASED IMAGE PROCESSING

An alternative method to reduce the effects of back scatter is to manipulate the images that are received by the camera. This can be done by the use of image-processing techniques either automatically or on command by the operator. Various techniques can be used to enhance the image but invariably one technique will not satisfy all conditions. This then requires knowledge of a) the conditions experienced in the medium and b) specified techniques developed for particular purposes. Complicated image-processing can remove the ability to image in "real time", resulting in a delay in the information transfer to the operator. Thus simplification is often the key, but if required a large number of techniques can be applied to produce the desired effect.

The human observer relies upon for wide range of visual cues, drawing from colour, perspective, shading, parallax and their own particular individual experiences. The nature of optical visualisation of the underwater environment results in many of these cues be either degraded or removed, reducing the ability of the operator to recognise what is seen. This in turn will reduce their ability to draw from experience and recognise the scene. The use of image-processing, rather than improving an image can enhance the recognisable features of an image, and lesson the detrimental effect of unwanted information.

When this is incorporated into Machine Vision, images can be analysed, interpreted and further manipulated to provide the operator with information that is not automatically provided purely through visual cues. The increasing capabilities of machine Vision Technology has allowed such systems to be applied to a wide variety of problems and tasks ranging from inspection, processes, monitoring and gauging. To do this though all areas must be specifically defined within algorithms, written purely for the task in hand.

This is a relatively new option and its application is only restricted by the speed of its development. Great advances have been made in image-processing systems in recent years allowing these systems to be utilised too much greater effect. Imaging tools are now available to enhance an image such as Edge detection, intensity gradient detection, filtering techniques and image addition and subtraction processes. Such systems used in conjunction with other underwater Vision techniques can greatly enhance the images achieved and improve the ability of the operator.

5.6 DEVELOPMENT OF UNDERWATER IMAGING SYSTEMS

The design of underwater imaging systems has always required a degree of trade-off between camera and light separation, contrast and power to achieve the best results within various environments. Work carried out in the 1950s and early 1960s by S.Q.Duntley at the Massachusetts Institute of Technology and later at the Scripps Institute of Oceanography in San Diego helped to define the basic limitations of underwater imaging. [(5.17)]

In the early 1970s this research was furthered at the Scripps Institute by attempts to improve the capabilities of underwater imagery. Within this programme the performance of conventional systems was analysed and an exploration of more novel system designs were explored. These novel systems included the use of laser technology through range gating and synchronous scan imaging techniques. [(5.18)]

The origins of underwater range gating date back to that late 1960s. In 1967 the system was first demonstrated by P. J. Heckman at the NOTS Morris Dame test facility in Pasadena. Despite equipment difficulties Heckman was able to demonstrate the principles of back scatter rejection through range gating. [(5.19)] Development of the system was initially hindered by short falls in technology denying a sufficiently powered laser imaging unit that could be incorporated on an ROV and the required length of pulse. If we consider that light propagates through water at approximately 22.5 centimetres in one nanosecond, then the required laser pulse over a range of one metre would be only a few nanoseconds [(5.19)]

G.I. Parslow [(5.20)] drew attention to the development in the early 1970s of an underwater laser viewing system consisting of a compact self contained battery operated illumination design. This Time Varying Intensity or TVI design was capable of scanning a laser beam over a target area in a raster pattern; the varying intensity of the reflected region would define the region on the image on a cathode ray tube sequentially as the raster scan progressed.

The TVI system was capable of producing images of target objects in great detail and helped to illustrate the potential for laser based underwater illumination systems. The conclusions though that were drawn from this and other work carried out in the period, was that the state of the art technology of the period, rendered the routine operations of such systems impractical. The limitations were outlined and included; instabilities of output, frequency downtime and power conversion inefficiency. Further difficulties arose with the supporting technologies required to operate the imaging systems such as high power transmission cables and optical scanning and gating techniques. These limitations restricted the development of such systems as commercial interest was unforthcoming. [5.20]

The early 1980s saw a resurgence of interest in the use of lasers for underwater viewing as blue green laser technology advanced. In 1983, The Scripps Institute carried out work on a range gated scanning system utilising a copper chloride laser.

Conventional systems incorporating a camera and standard illumination source are generally capable of effective imaging up to 1 attenuation length. The achievement of higher attenuation lengths though are “contrast limited”. Where the separation between light source and camera are increased, effective imaging can be increased to the range of 2-3 attenuation lengths, but are still greatly affected by back scattering. The development of range gating and synchronise scanning techniques, collectively known as active imaging techniques, offer a performance of greater than 3 attenuation lengths. [5.21]

The abilities of these systems though, are unquestionably dependent upon the level of turbidity encountered in the region that is being visualised. Imaging through a highly turbid medium such as surf zone or coastal waters reduces the effective range of these systems markedly. Riaziat et al (1997) [(5.22)] suggests that "imaging through turbid water is limited by blurring rather than optical attenuation. In other words, the limiting factor is that of scattering Length, rather than the absorption Length."

The effectiveness of range gated imaging systems in reducing back scatter is reliant upon the duration of pulse of laser light that is used. This pulse of light should be considerably smaller than the time of flight from source to target. Although pulsed laser based range gated systems in testing have produced imaging in the region of 4 attenuation lengths and provide better resolution at range (>10 metres), range gating systems are ineffective against forward scatter. [(5.23)]

Forward scatter can be reduced though using synchronous scanning techniques. The reduction in common volume achieved through these systems, limits both forward and back scattering events. Moore et al (2000) argues that "for this reason laser line scan synchronous scanning systems show superior contrast resolution over range gated systems". Moore further notes that although the technique is not a new one, " the advent of high-speed sensitive detectors, precision scanners, inexpensive computing technology, and the availability of blue-green lasers, now allows synchronous scanning systems to be realised in practical applications".[(5.23)]

With synchronous scanning techniques, the pulsed laser is used to flash the field of the view of an imaging detector which will receive reflections from all points within the common volume. If this pulse rate is faster than 30 pulses per second the collected image will appear in close to real time. High pulse energies are needed to flash the entire field of view at one time, limiting its size to between 12° and 20°. In comparison, conventional camera imaging systems have a field of view of between 30° and 60°. The resolution of any image is determined by the pixel density of this detector array and by back scatter. (5.24)

In synchronised scanning systems a laser beam is linearly scanned over a target object to produce an image, the resolution of which is determined by the beam quality of the laser. The improved resolution achieved through this system is not its only advantage, as wide areas can also be scanned over a relatively short time scale. This area can be as much as five times that of a range gated system due to its large swath width. (5.25) Difficulties can arise though through the shape of the target area and the geometry of the scanning angle. The characteristics of the projected stripe can alter dramatically over a non uniform target, creating difficulties in continuity and image construction.

In an effective vision system the image should provide a close to accurate interpretation of a target object. To achieve this, the system requires a high quality image acquisition and processing subsystem, capable of not only enhancing the image but effectively compiling subsequent images in a meaningful way. (5.26). As ROV/AUV platforms are never precisely stationary, the subsystem should also be capable of close to real time imaging to avoid meaningless images being compiled.

Underwater optical imaging systems have practical uses both for navigation and observation but the application of active systems for this purpose is somewhat in its infancy. Such techniques have been in competition with acoustic imaging systems, against which they show poor propagation distances. Implementation of all laser based imaging systems on ROV/AUV platforms was delayed not only due to technical limitations, but also due to cost constraints. Laser technology has moved on considerably since the early Seventies finding applications throughout industry, medicine and the military. Reliability is becoming less of an issue but the systems can still be delicate and temperamental.

High-power, high-efficiency, compact lasers are now available, offering a viable alternative to acoustic systems. To enhance their use, the advancements in image-processing and machine Vision Technology have offered further options to image acquisition. Accurate feature reconstruction and data acquisition in real time are now an option. [5.27]

5.6.1 MACHINE VISION

Machine Vision has been defined as; "the use of devices for optical, non-contact sensing to receive and interpret an image of a real scene automatically, in order to obtain information and or control machines or processes."[5.28]

The range of applications for underwater imaging requires the use of various techniques to improve the quality of images that are received. The interpretation of these images though, still requires a level of skill, experience and knowledge from an operator for tasks such as sub sea inspection and object identification. To enhance the ability of the operator to perform this task, image-processing systems are being applied to manipulate those images received. The technology for these systems originated through development for the space programme and military applications, but has been restricted from broader applications by cost. [5.20]

In recent years there have been major advances in the technology of electronic image collection and processing, allowing several new concepts in ocean imaging to be explored. Relatively cost-efficient image-processing, hardware and software have now become available allowing underwater imaging systems to incorporate a new dimension in the enhancement of sub-sea viewing.

5.7 LASERS

The first successful optical laser constructed by Maiman (1960) [(5.29)], consisted of a ruby crystal surrounded by a helicoidal flash tube enclosed within a polished aluminium cylindrical cavity cooled by forced air. The ruby cylinder forms a Fabry-Perot cavity by optically polishing the ends to be parallel to within a third of a wavelength of light. Each end was coated with evaporated silver; one end was made less reflective to allow some radiation to escape as a beam.

A short while after the initial announcement of the first successful optical laser, other labs around the world jumped on the bandwagon trying out many different substrates and ions such as rare earths like Nd, Pr, Tm, Ho, Er, Yb, Gd even Uranium was successfully lased. Many different substrates were tried such as Yttrium Aluminium Garnet (YAG), glass (which was easier to manufacture), CaF2. As manufacturing techniques improved these lasers rapidly made the transition from the lab bench to commercial applications.

Lasers have developed significantly to become essential tools for scientific development and have found everyday uses in supermarket scanners, laser printers, and compact disk players. Industrial applications include welding and cutting, materials processing, and analytical instruments.

5.7.1 PRINCIPLES OF THE LASER

As energy (usually electrical) is pumped into a specific material, light is emitted and semiconductors are considered to be an extremely good source of laser light. If a photon of the correct wavelength hits an atom, it will raise an electron to a higher energy level. The atom is then said to be in an excited state. When the electron falls back down it emits light of the same wavelength, in a random direction.

If a photon hits an atom that is already excited, that atom will emit a further photon, identical to the original: with the same wavelength, propagating in the same direction. These photons will then collide with further exited atoms resulting in an exponential amplification of light. Hence the term "light amplification by stimulated emission of radiation" or LASER

Laser light has the following properties:

- The light released is monochromatic. It contains one specific wavelength of light (one specific colour). The wavelength of light is determined by the amount of energy released when the electron drops to a lower orbit.
- The light released is coherent. It is "organized" -- each photon moves in step with the others. This means that all of the photons have wave fronts that launch in unison.
- The light is highly directional. A laser light has a strict beam and is very strong and concentrated. A flashlight, on the other hand, releases light in many directions, and the light is very weak and diffuse.

In a standard lamp photon release by atoms is random whilst in stimulated emission; photon emission is organized in nature.

5.7.2 LASER TYPES

There are several different types of lasers. The laser medium can be a solid, gas, liquid or semiconductor and it is the lasing material that defines the laser.

- **Solid-state lasers** have lasing material distributed in a solid matrix (such as the ruby or neodymium:yttrium-aluminum garnet "Yag" lasers). The neodymium-Yag laser emits infrared light at 1,064 nanometres (nm). A nanometre is $1x10^{-9}$ meters.

- **Gas lasers** (helium and helium-neon, HeNe, are the most common gas lasers) have a primary output of visible red light. CO2 lasers emit energy in the far-infrared, and are used for cutting hard materials.
- **Excimer lasers** (the name is derived from the terms *excited* and *dimers*) use reactive gases, such as chlorine and fluorine, mixed with inert gases such as argon, krypton or xenon. When electrically stimulated, a pseudo molecule (dimer) is produced. When lased, the dimer produces light in the ultraviolet range.
- **Dye lasers** use complex organic dyes, such as rhodamine 6G, in liquid solution or suspension as lasing media. They are tuneable over a broad range of wavelengths.
- **Semiconductor lasers**, sometimes called diode lasers, are not solid-state lasers. These electronic devices are generally very small and use low power. They may be built into larger arrays, such as the writing source in some laser printers or CD players.
- A **ruby laser** is a solid-state laser and emits at a wavelength of 694 nm.

Other lasing mediums can be selected based on the desired emission wavelength, power needed, and pulse duration. Lasers such as CO2 lasers are extremely powerful and can be capable of cutting through steel. The reason that the CO2 laser is so dangerous is because it emits laser light in the infrared and microwave region of the spectrum. Infrared radiation is heat, and is capable of melting whatever it is directed towards.

Other lasers, such as diode lasers, are very weak and are used in today's pocket laser pointers. These lasers typically emit a red beam of light that has a wavelength between 630 nm and 680 nm.

5.7.3 Nd:YAG LASERS

The development of diode pumped lasers has fuelled research into new Nd: doped materials with improved spectral properties for diode pumping. Besides larger cross sections, higher concentrations of the active ion can improve the efficiency of diode pumped lasers with short crystals. It is also easier to obtain mode matching between pump and laser beam [(8.3)].

5.7.4 DIODE PUMP LASERS

The development of high-powered laser diodes has revolutionised the use of solid state laser technology in underwater viewing systems. With such lasers it is possible to obtain higher efficiencies and produce rigid all solid state devises in a more compact design. Pulsed diode pumped Nd:YAG lasers produce multimode Q-switched output up to hundreds of millijoules at wall plug efficiencies of up to 6% [(5.30)].

Compact solid state diode pumped lasers in the green blue spectral region are of great use for underwater display and high density optical data storage applications as they can be easily fitted for ROV or AUV deployment. In recent years optical efficiencies of more than 20% with respect to pump power were obtained in Nd:YAG and Nd:YVO lasers by internal frequency doubling with a potassium titanyl phosphate (KTPO crystal [(5.31)]. Cost has limited their use but this situation has improved considerably in recent years.

5.7.4.1 The Advantages of Diode-Pumped Lasers

- **Greater Efficiency:** Diode arrays are significantly more electrically efficient than conventional lamps.
- **Lower Voltage Requirements:** Diode-pumped lasers do not require the same high voltages necessary for an equivalent flash lamp system. The input power required for a diode-pumped laser is typically 5-10% of the equivalent arc lamp system.

- **Compact Design:** Diode-pumped systems allow for smaller, more compact housings.
- **Beam Quality:** Diode-pumped lasers produce a superior beam quality. This is particularly true when diodes are end-pumped.
- **Less Waste Heat:** With diode-pumped lasers cooling is achieved with closed loop standard distilled water, or a mixture of water and glycol -- without the need for deionization and external city or tower cooling water.
- **Durability:** Diode-pumped lasers are far more rugged.
- **Ease of Conversion:** It's a simple process to retrofit a flash lamp system to utilize diode arrays. Most flash lamp systems can be easily converted to a diode-pumped system. [5.32]

5.8 THE CRANFIELD UNDERWATER LASER IMAGING SYSTEM

In 1988 Jaffe[5.33] proposed the scanning a stripe of incoherent light across the field of view of the camera and predicted that improved imagery could be achieved of up to 4 attenuation lengths in "some situations". As highlighted though by Spours[5.34], the use of an incoherent light source would significantly reduce the effectiveness of the system and suggests the use of a laser source would provide sharper stripe definition and more constant level of illumination across its length.

The potential for laser technology for the improvement of underwater visual imaging was recognised at Cranfield University and led to development of a hybrid underwater viewing system.

The system consists of a diode-pumped Nd:YAG laser scanning unit used in conjunction with a SIT or silicon intensified target camera. The Scanning Unit allows for the deflection of the collimated beam in the horizontal (**x**) and vertical (**y**) direction. Controlled from the surface via an umbilical link, the system provides the user with a high-level of control and potential image data retrieval.

Due the larger field of view of the camera, the common volume created by the intersection of a field of view and the laser illumination is greater than that of a comparable synchronous scanning system. Therefore the reduction in a level of back scatter effect whilst effective will prove to be less than that of the synchronous scanning system. This though can be traded against a low level of complexity and reduced development that the Cranfield system offers.

Both methods rely upon the principle of the illumination of a small region of the target object by the laser to reduce the effects of back scatter and glow from any object that the illuminating beam falls upon. The Cranfield system though is unlimited by the depth of field of focus requiring no need for compensation through complex equipment and control mechanisms.

The aim of this project was to develop computer-based image-processing techniques that not only provide an automated method of image construction, but to enhance the effectiveness of the system by improving image quality and object recognition. Initially this was carried out through the use of the VisionBlox image-processing system based on visual basic programming. Through restrictions in the abilities of this system and to meet the requirements of the sponsors, development was switched to Labview 6

5.8.1 THEORY OF OPERATION

Laser illumination is scanned over target area within the field of view of the camera; this is performed in a rectangular raster pattern and is illustrated in figure 5.7. As illumination falls upon a target object in its path, the continuous scanning can be captured partially and progressively by the image-processing tool allowing an interpretation of the object to be constructed.

In a clear non scattering medium only light that is reflected off an object in the water column in the field of view of the camera is reflected resulting in a stripe of light. Successive stripes can then be "grabbed" and held by image-processing system and built into a representational image as shown in figure 5.8.

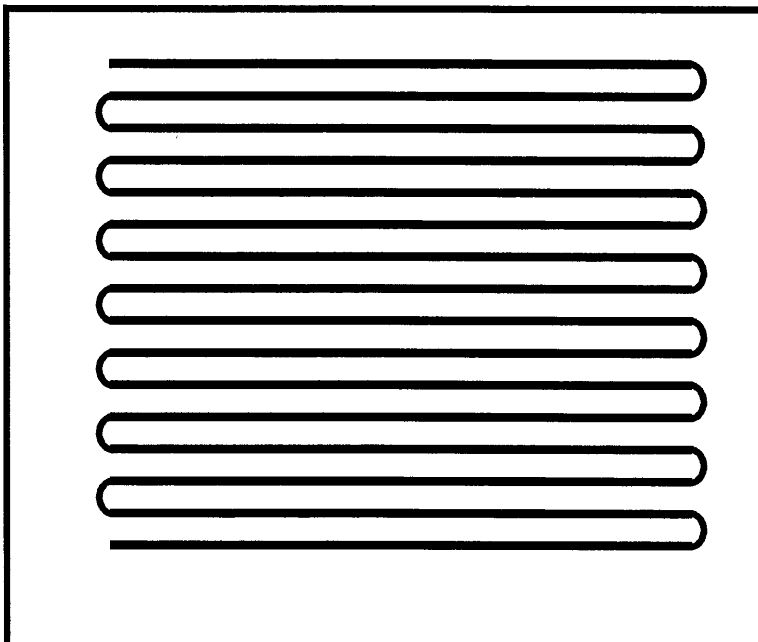


Figure 5.7: Scanning pattern of the Cranfield laser imaging system

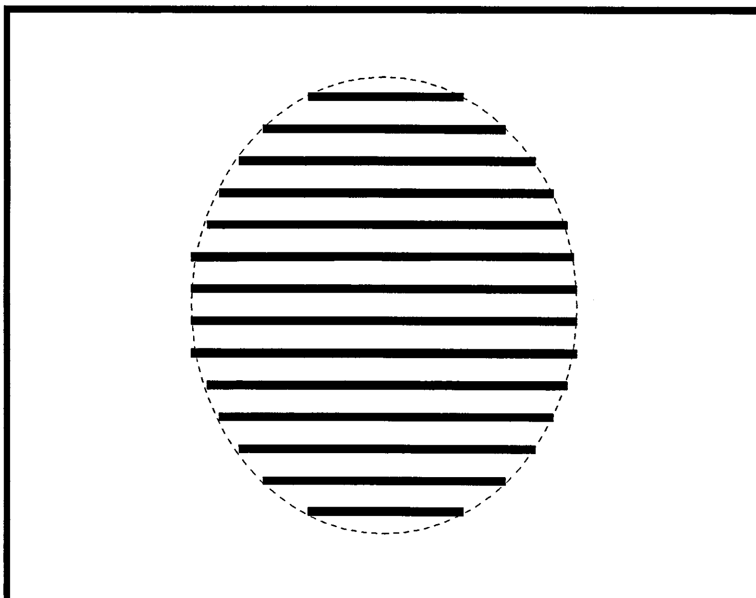


Figure 5.8: Target object image represented in the form of stripes

The effect of the system within a scattering medium is that light is reflected off particles that are encountered within the path of the light resulting in a level of scattering occurring within the field of view of the camera. To reduce this, the laser source and the camera are separated. Increasing separation can further improve the image but is restricted by practical mounting on a vehicle such as an ROV. For experimental purposes separation of laser and camera was held constant at 60 cm.

It must be realised that the projection of the laser stripe upon any object does not always result in a perfectly defined stripe being received by the camera. As the stripe intersects with the surface of an object it is the surface that determines the resultant shape of the stripe. This aids the operator in determining the geometry of the object but can create difficulties in the construction of a clear image.

5.8.2 SYSTEM COMPONENTS

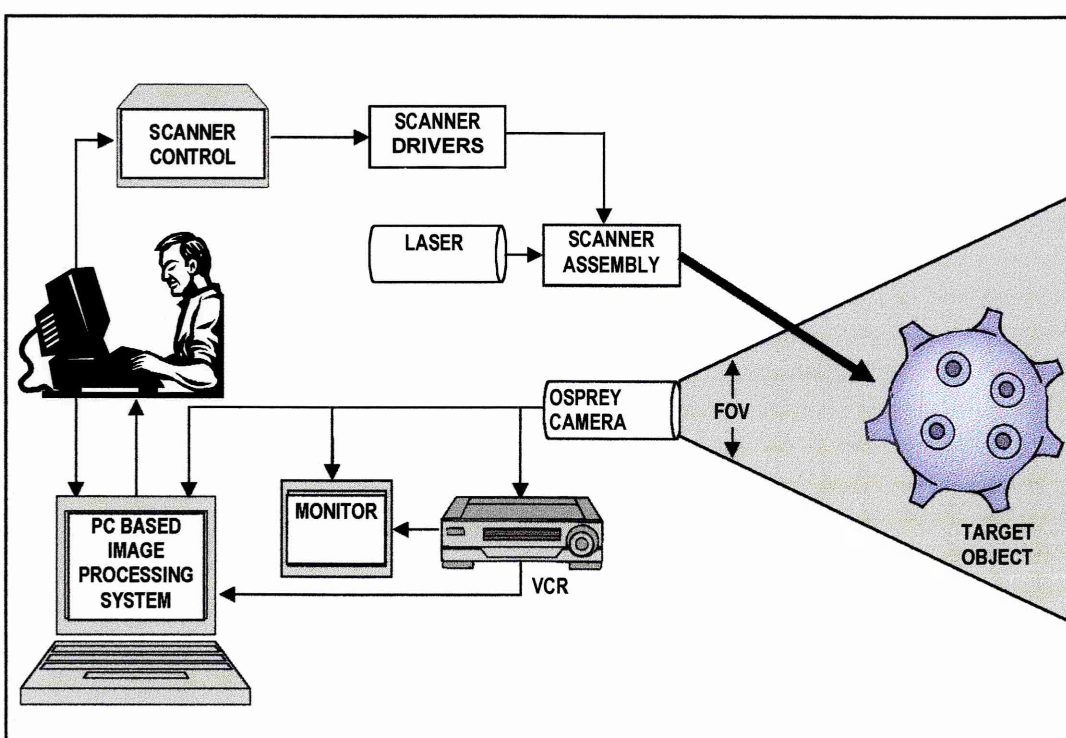


Figure 5.9: Components of the Hybrid Cranfield underwater imaging system

The principle components of the Hybrid Cranfield underwater imaging system, shown in the diagram above are: The Nd:YAG laser, the laser scanning units, The SIT camera, the PC based image processing system and the operator.

The Laser

The Cranfield Underwater Laser imaging system utilises a 100 mW Adlas DPY 315, frequency doubled, diode pumped Nd:YAG laser and is housed in a robust, waterproof casing. Operating within the blue/green region of the spectrum the laser uses the colour band within which attenuation of light is minimised in water. Table 5.2 Below lists the characteristics of this item

Laser Type:	**Frequency doubled, diode pumped Nd:YAG**
Wavelength:	**532nm**
Power	**>100mW**
Beam divergence:	**□ 2.2mrads**
Stability:	**<2 %**
Laser head dimensions:	**100 x 40 x 32.5mm**
Power supply dimensions:	**100 x 128 x 41mm**
Operating voltage:	**+ 12 – 28 V**
Power consumption:	**< 80W (typical 20 W)**

Table 5.1: Summary of Adlas DPY 315 Diode Pumped Laser

The relatively low emission cross section of Nd:YAG (40%) is not a major disadvantage, as Nd lasers are operated far above laser threshold in most configurations and a slightly higher threshold does not decrease the overall efficiency greatly [5.31].

Laser Scanning Units

The scanner subassembly is composed of two rotating, four-faceted mirrors, rigidly attached to a common rotating shaft. The illumination laser is oriented such that its output beam is incident on the smaller of the mirrors, deflecting the beam in the desired direction. As the mirrors rotate, the scan spot traces a continuous line across the field of view of the camera.

Y axis scanning results in progressive movement across the entire field of view and the target will be scanned in two dimensions. By alterations in the scan rate, it is possible to control the spacing between the lines that are grabbed by the image processing system, enhancing the level of image information that can be extracted.

SIT Camera

With this system a conventional SIT camera is used as a receiver. This offers a low cost and a high level of adaptability to stationary platforms such as an ROV. Also, the distance to the target is not required in contrast to alternative laser imaging systems that require the range to be found [5.35].

5.8.3 DIGITAL IMAGING

Image-processing of underwater photographs began by attempts to subtract an equivalent quantity of light from every element of the picture." With the use of high contrast papers and adjustments to the printing, the darkest points of the image could be given a suitably dense print area. [5.36] images from a camera are now digitised by converting the image into a discreet number of pixels. A grey level value and a numeric location are assigned to specify the brightness of each pixel.

A digital image has three basic properties: image resolution, image definition and a number of planes. The image resolution is defined by its spatial resolution for the number of rows and columns of pixels. For example if an image is composed of ***x*** rows, and ***y*** columns then it has a resolution of ***xy***.

The definition of an image or "pixel depth" indicates the number of colours or shades that are visible in the image. Pixel depth is the number of bits used to code the intensity of the pixel. The definition of a pixel ***n*** can take 2^n different values. Therefore;

$$\text{If } n = 8 \text{ bits, then the pixel definition} = 2^8 = 256$$

As a result the pixel can hold any of 256 values ranging from 0 to 255. 0 corresponding to black and 255 corresponding to white. Subsequently if ***n*** = 16 bits, the pixel can then take any of 65,536 different values, ranging from 0 to 65,535.

The number of planes in an image is defined as the number of arrays of pixels that compose an image. A "true colour" image comprises three planes formed of red, blue and green, whilst in grey-level images intensity values for red, blue and green are combined to produce a single value and thus are represented by a single plane.

Basic image processing principles

The inclusion of an image processing element into any underwater imaging system is to artificially enhance the images achieved by making best use of the visual information available through the captured image. In the case of the Cranfield laser stripe imaging system, live images are fed into the computer from which individual still images can be progressively grabbed, to obtain a single projected stripe in the course of a scan. These individual grabs can then be processed and added to previously processed grabs and built into a cumulative image of a target object.

Image processing tools such as Vision Blox and Labview, present images to the developer in an array of pixels and offer a range of tools that can be utilised to develop effective techniques to enhance the visual information available in a way best suited to the aims of the developer.

6 PROJECT DEFINITION

The need for non acoustic sensing and recognition of underwater objects for the military has been discussed at length previously. The development of smaller mines that offer low acoustic cross sections and the problem of sonar reverberation in shallow water regions has fuelled the need to research alternative detection techniques. Underwater viewing systems would seem to offer a partial solution to this problem but the limited range of standard forms of artificial lighting has restricted its use.

The Defence Evaluation and Research Agency (DERA) became interested in the Cranfield laser stripe imaging system for deployment on their Non Acoustic Sensor Platform (NASP) and later for their Enhanced Sensor Platform (ESP). This interest was gained after demonstrations of the advantages of the system in clear and turbid waters. These autonomous platforms would be designed for mine detection and countermeasures within shallow waters and the surf zone, providing valuable, up to date intelligence on the nature ad extent of the mine threat within these regions.

This research programme aims to develop the processes of image manipulation for the Cranfield laser stripe system and to achieve effective machine vision applications to overcome problems within the laser stripe system. Initially targeting the construction of images from individual stripe grabs, moving onto processes that will aim to enhance these completed images to allow more effective recognition of underwater objects. Initially the 'Vision Blox' image processing system was utilised for the creation of the algorithms used with the laser imaging system. This was then changed to the sponsors preferred software 'Labview'.

6.1 INITIAL CONSIDERATIONS

The development of a test procedure for the image processing techniques required a consideration of the problems to be overcome, within the remit of the project aims. The use of a laser stripe to illuminate a region on a target object offers a unique interpretation of that region to the developer.

Certain aspects of the nature of the system had to be explored prior to development of the algorithms. These were;

- The layout of the underwater laboratory.
- The capture and storage of images
- The adoption of a standard target
- The use of artificial turbidity

6.1.1 VISION BLOX ALGORITHM DEVELOPMENT

The construction of an image from the accumulation of individually illuminated regions required an algorithm based technique that could be defined in three separate sub-processes. Referring to figure 6.1; from the initial stripe projection A), the process must perform an identification of the stripe region. The stripe region must then be efficiently isolated B) allowing the processing system to secondly efficiently extract the maximum visual information illuminated by the stripe C) and thirdly compile an effective and recognisable cumulative image of the target object D).

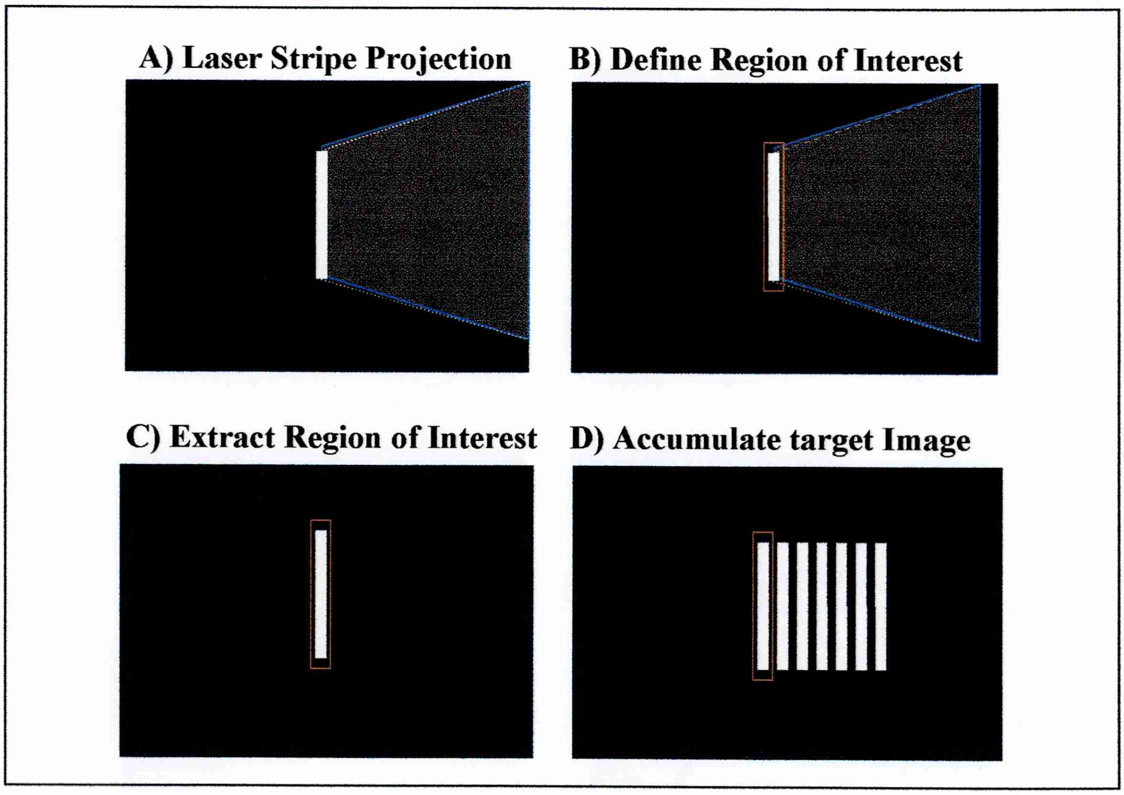


Figure 6.1: Laser stripe isolation, extraction and accumulation process

Within the Vision Blox image processing system several integral methods were identified that could be utilised for the identification of the stripe region were considered and explored. These were;

- Initial processing techniques, through non inherent processes
- Intensity threshold identification
- Blobs tool intensity separation
- Calliper tool (edge pairing characteristics)
- Single strait edge detection

In the evaluation of these methods certain considerations were taken into account. These were;

- Effective discrimination of stripe and non stripe regions
- Ability to define stripe region in highly turbid conditions
- Overall stability of the tool when built into a processing algorithm
- Speed of operation when built into a processing algorithm
- The flexibility of the system
- Ability of the operator to control the level of information to suit varying conditions
- The level of automation that could be built into the process

The isolation of the stripe defines the Region of interest or ROI, which must contain the optimum visual information for extraction. The process of stripe isolation was required to be quick and efficient as further processing of each stripe would be required before successive grabs could be taken. Any instability in the process could result in loss of visual information, slower processing speed or in the worst case, system crash.

The extraction process would remove only the required visual information, specified by the ROI from the grabbed image of the stripe and transfer this data in the form of specific pixel intensity to an accumulation screen. Primary consideration during this process had to be given to;

- Ability to extract only the information from the identified region of interest
- Effective transfer to accumulation screen
- Speed of operation
- Stability of operation
- The process should be fully automated

The final stage in the process required the successful addition of sequential extractions resulting in the building of an effective and recognisable interpretation of the target image. This required the consideration of;

- Loss of visual information
- Accumulation of unwanted information
- Effectiveness of the stripe addition process
- A level of control for the operator
- A level of manipulation to enhance visual characteristics

6.1.2 LABVIEW ALGORITHM DEVELOPMENT

As with the development of algorithms within VisionBLOX, several techniques ere identified within LabVIEW 5.1 and 6i for the processing of images obtained through the system. These were;

- Initial processing techniques, through non inherent processes
- Intensity threshold identification
- Threshold isolation
- Gamma correction isolation
- Filter enhancement

All techniques required the considerations made for Vision Blox algorithms;

6.2 WATERFALLING TECHNIQUE

The development of the system as a seabed scanning system required the writing of dedicated algorithms. The considerations made during their development were;

- System configuration
- Tracking the stripe across the viewing window
- Isolation of the desired stripe information
- Effective stripe extraction
- Stripe addition
- Placement of the stripe in the cumulative image
- Production of virtual movement within the cumulative window
- Operator accessible image

7 DEVELOPMENT OF THE UNDERWATER VIEWING LABORATORY

The research project being primarily a PC based one, still required the feeding of running images that represented the laser imaging system working within the actual environment. To a certain extent this could be achieved by the use of video images captured either in the ocean or laboratory test tank. This though created restrictions in the speed of algorithm development particularly as the project progressed.

The use of video footage restricted the environmental conditions to those achievable at the time of capture and so were relatively uncontrollable, a situation not helpful when attempting to define relative progress. In the absence of oceanic conditions then It was necessary to recreate an environment that could represent the problems of a backscattering medium under laboratory conditions. This was carried out in The Cranfield Offshore Technology Centre tank measuring 4 m x 4 m with a 3 m depth and can be seen in figure 7.1.

The tank facility incorporates a dry laboratory area with viewing window, situated adjacent to the tank where the subsurface apparatus was situated. The tank facility was overlaid throughout the duration of testing by a floating cover and sealed with the use of flexible skirts, to prevent the penetration of ambient light. The dray well was entirely boxed both to ensure no light entered the testing area and as a safety measure for the use of lasers. This light sealed viewing well also allowed observations to be carried out whilst the system was in operation. The walls and floor of the test tank are blacked to create a surface with minimal light reflective properties.

Target objects were suspended in the tank at pre-measured distances from the camera and laser. Initially video images were taken of all test runs carried out within the tank but it was noticeable that the signal was weakened and provided a level of electrical noise to the images.

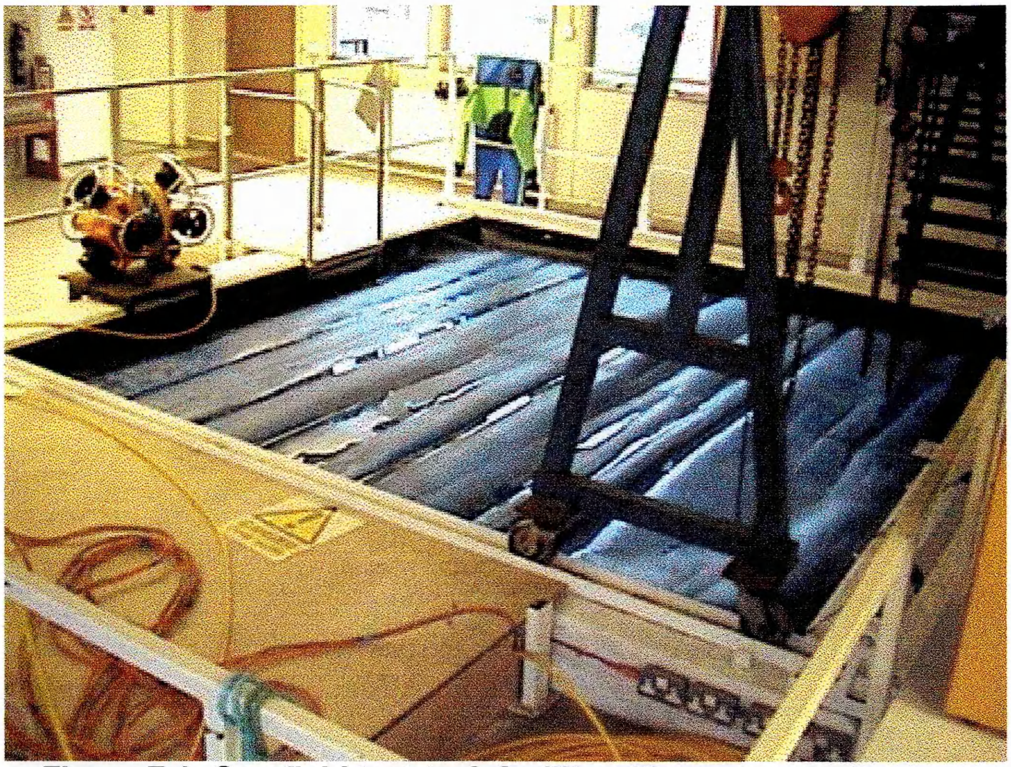


Figure 7.1: Cranfield test tank facility with cover over to remove ambient light

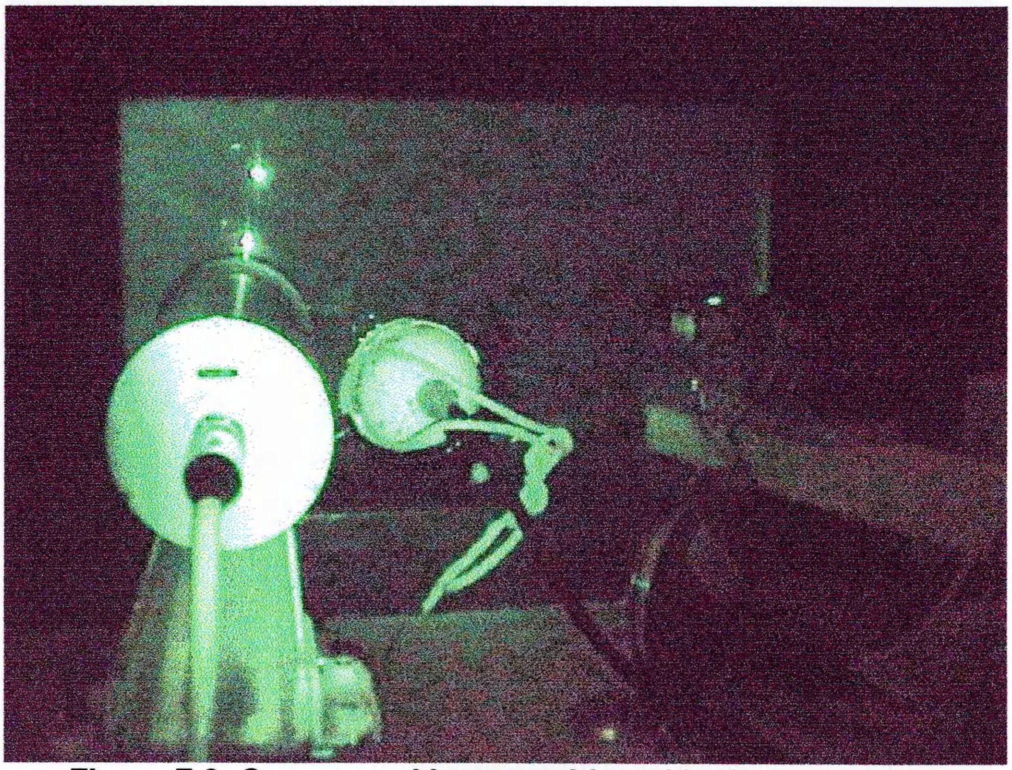


Figure 7.2: Camera and laser positioned in the test tank observation window

7.1 INCANDESCENT LAMP

For the purposes of comparison images a Viking 1000W incandescent lamp was adopted. During each testing stage of the algorithms a lamp image was captured not only as a comparison image but also as a point of reference for the reader. The production of laser stripe images alters the scene dramatically often removing reference images more recognisable to the reader. Thus it is important to provide the reader with a reference point that they are more familiar with and a visual image of the scale of the underwater imaging problem.

7.2 AN ARTIFICAILLY TURBID ENVIRONMENT

Turbidity can be defined as the "expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the medium" [7.1]. Turbid conditions in the ocean are a culmination of various substances and environmental conditions that are experienced in a specific locality at a precise time and so the recreation of the situation in a laboratory environment can never be exact.

In the limited region of the laboratory tank and the priorities of the project directed towards object recognition the principal concern would be that of backscattering, hence an artificial scattering agent would be appropriate. Previous work carried out on the system used Bentonite for this purpose and for the reasons of continuity it was decide that this would be suitable.

Figure 7.3: Bentonite Powder

Bentonite is a material composed of clay minerals, predominantly montmorillonite with minor amounts of other smectite group minerals and forms when basic rocks such as volcanic ash in marine basins are altered. Supplied in dry granular form, it swells considerably when exposed to water and creates a highly effective scattering medium due to its Light grey appearance. The particles are 0.5 microns but are known to be discular in form, measuring 0.001 microns thick. The material has a strong tendency to coagulate which means that exact particle sizing in water is not possible but studies of slurries suggest sizes of 0.5 microns upwards. [(7.2)]

Measures of the Bentonite powder were added to the water in increments of 20g. Prior to its introduction smooth slurry was formed by mixing with distilled water in a standard household food processor. This was carried out to reduce the coagulating tendencies of the Bentonite to a minimum and to ensure, as far as allowable, a consistent mix. After its introduction a period of 1 hour was allowed before conducting sampling and system tests to ensure the stability of the turbidity level .After this period, water samples were taken and turbidity levels measured by a Hach Model 2100N Laboratory Turbidimeter, with the levels of turbidity measured in Nephelometric Turbidity Units (NTU). The results of these tests are shown in figure 7.1.

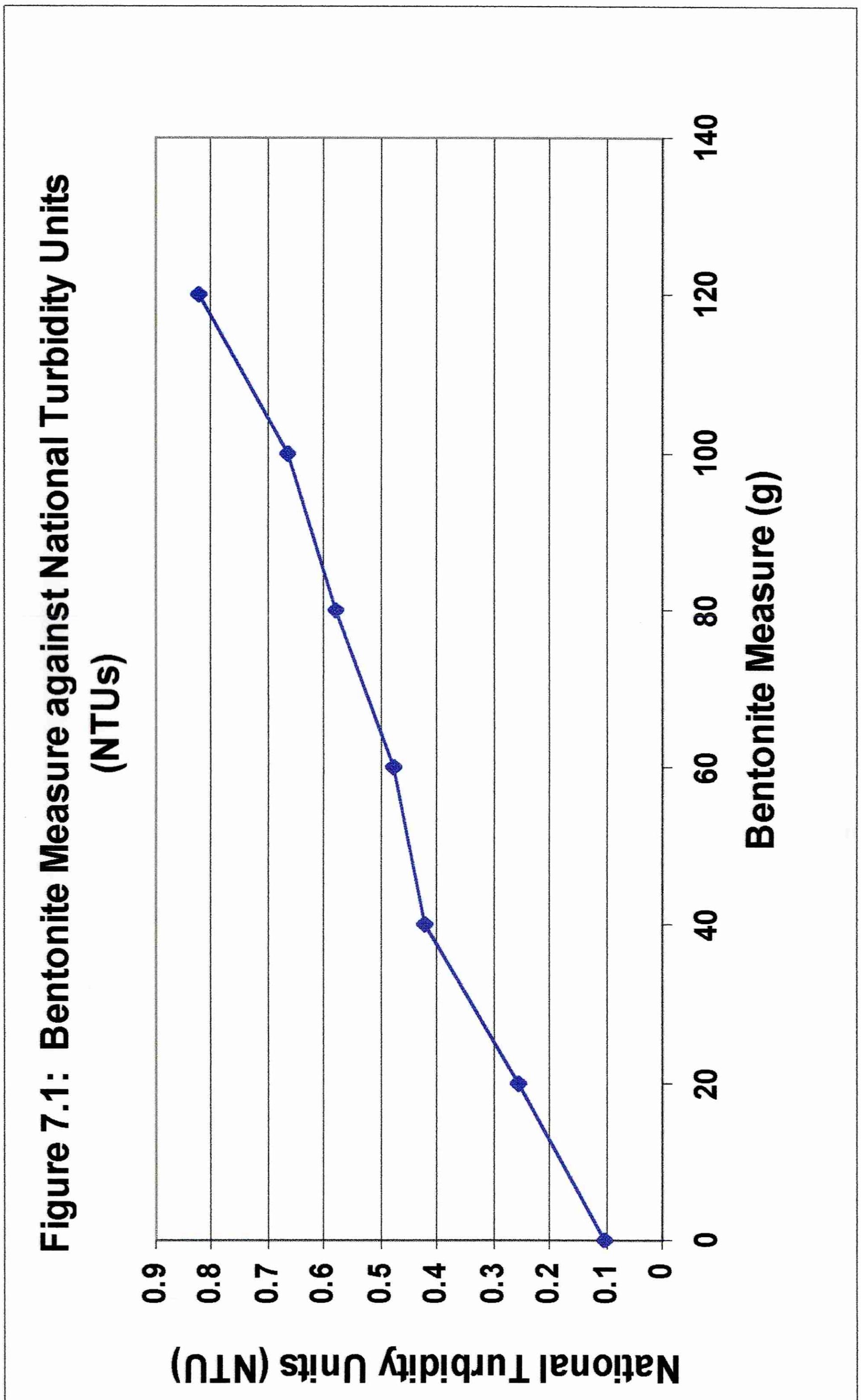


Figure 7.1: Bentonite addition in terms of Average National Turbidity Units (NTUs)

7.3 TARGET OBJECTS

Much work has been carried out in the past as to the nature of the target objects to be used within the system, and these were developed primarily for the purposes of the research in hand. Initial stripe investigation and the development of image processing techniques to carry out the stripe isolation, extraction and cumulative image compilation, was carried out either on the blackened back wall of the test tank or on flat targets.

The exploration of the nature of the stripe as it falls on different geometrical features identified varying stripe characteristics as the geometry of the target object changes. This created difficulties in the use of the addition algorithms to create a cumulative image as a large amount of unwanted visual information was being carried through the final image.

Referring to figures 7.4 and 7.5, as the stripe falls upon objects of altering geometry the nature of the shape of the stripe can change dramatically. The development of a processing technique that can effectively isolate the stripe region alone was required along with a process that could realistically compile an image from geometrically altering stripes

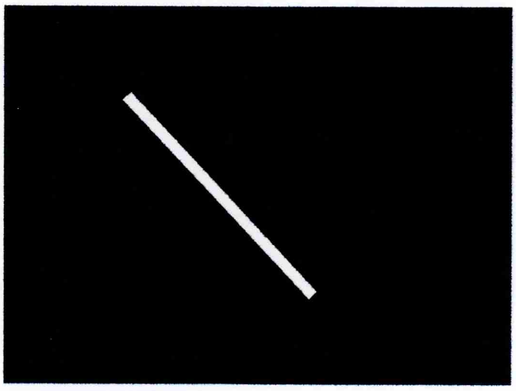


Figure 7.4: Projected stripe orientation on a target with a flat angled surface

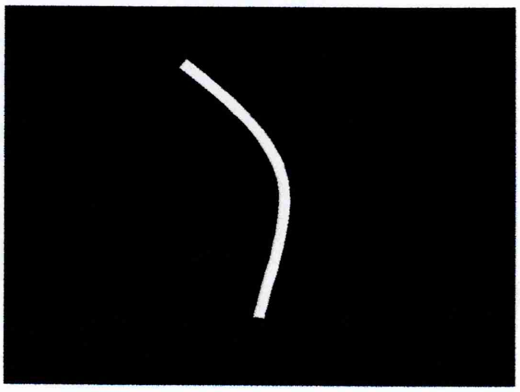
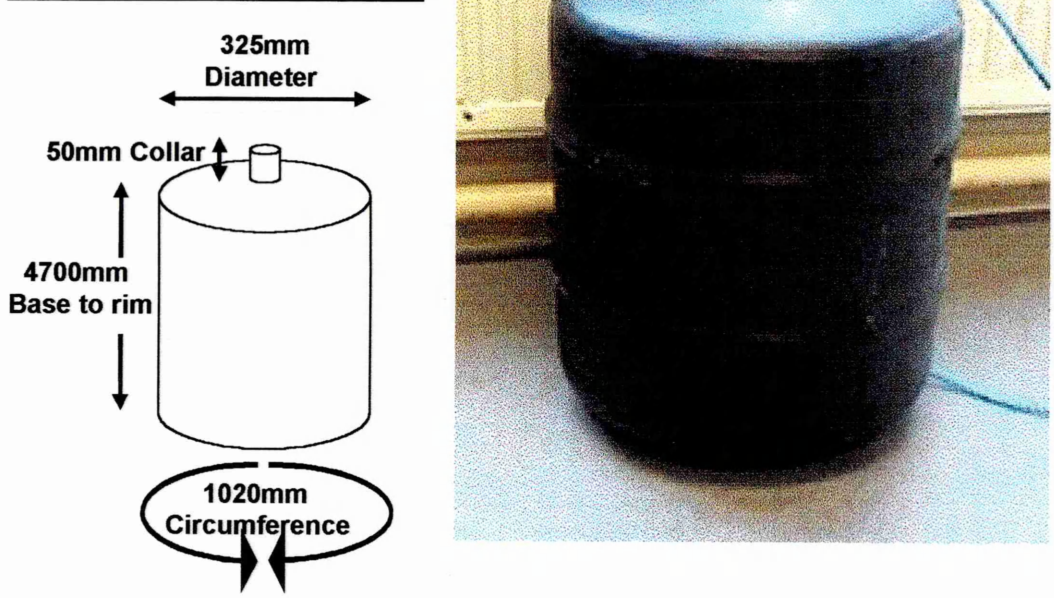


Figure 7.5: Projected stripe orientation on a target with a curved surface

Therefore it was important to select a target object that could incorporate a three dimensional aspect to the compilation of the images. In recognition of the overall aim of the project i.e. the development of a surf zone mine hunting tool it was decided to adopt a classical mine shaped object. In the absence of the real thing though; a beer barrel would suffice. This provided a cylindrical geometry with altering surface features allowing both shape and detail analysis of the final image

Figure 7.6: Beer Barrel Target "Pseudo Mine"



The barrel was painted matt black to reduce glaring within the limited dimensions of the test tank and to allow the observation of scattering light in the captured images. Whilst brighter target objects would be easier to pinpoint with the use of the laser, glaring would reduce target object shape definition and surface detail. Further to this the use of a black target against the blackened back wall of the test tank allowed firstly a comparison of the same stripe on a flat and curved surface and secondly provided a challenge for the algorithm to identify the target in levels of raised turbidity.

To assess the affect of raising the turbidity in the tank a range of images were compiled to give a visual definition of turbidity levels. The target barrel was positioned at altering ranges in the field of view of the camera and the arc lamp used as the illumination source. The ability of the system to scan a laser stripe on the barrel at the same range can then be compared. Each image can then be used to compare against the different processing techniques developed within this project

Two further target objects were selected and used to obtain their images through the developed algorithms. An orange buoy provided a non blackened target and was painted with black writing to explore the extraction of target detail along with the use of a black and white horizontally striped target. These are shown below in figure 7.7

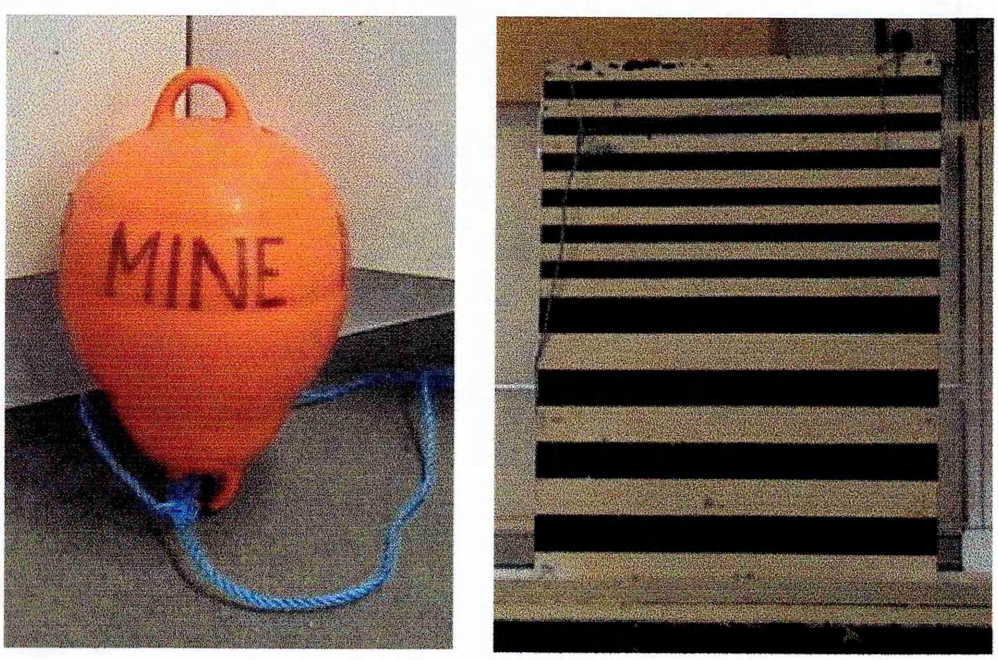


Figure 7.7: Alternative targets

7.4 IMAGE CAPTURE

Images were captured by the use of a Simrad 1623 Silicon Intensified Target camera (SIT) with a 12.5-80mm focal length and a standard CCIR output. Real time images were then transferred to the computer via an umbilical connection. Image processing software then grabs the images which are displayed on the computer screen. The maximum distance available in the test tank, between camera and target object, was 4m, with a field of view angle from manufacturer's specifications of 19.29° from the norm on the vertical and 24.82° on the horizontal, the resulting camera field of view of 3.7m x 2.8m is achieved.

At a given range from the target object the field of view (FOV) can then be evaluated.

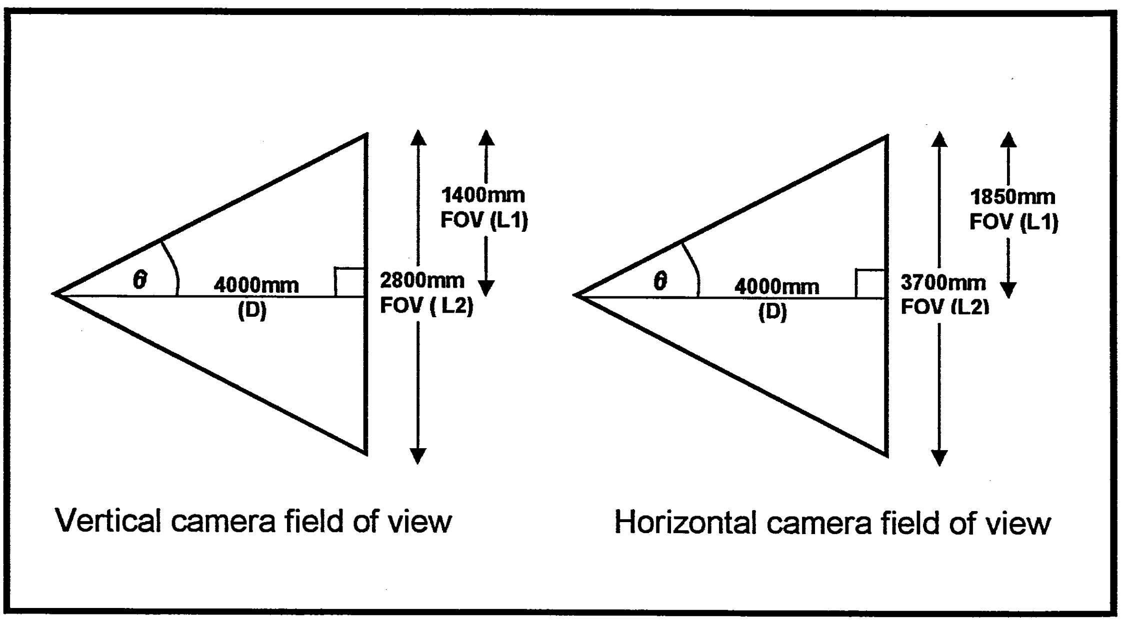


Figure 7.8: Simrad 1623 Silicon Intensified Target camera vertical and horizontal field of view at 4m from manufacturer's specifications.

Where ***D*** is the distance between target object and camera and ***θ*** is equal to 19.29° on the vertical and 24.82° on the horizontal, the length of the field of view can be extrapolated from the following equation;

$$FOV\,(L2) = 2\,(\tan\theta \times D)$$

Equation 7.1

Table 7.1 shows the calculated field of view length at progressive distances ***D*** from the camera to the nearest whole number;

Distance (*D*) mm	**Vertical FOV (*L1*) mm**	**Vertical FOV (*L2*) mm**	**Horizontal FOV (*L1*) mm**	**Horizontal FOV (*L2*) mm**
500	175	350	231	462
1000	350	700	462	925
1500	525	1050	693	1386
2000	700	1400	925	1850
2500	875	1750	1156	2312
3000	1050	2100	1387	2775
3500	1225	2450	1619	3237
4000	1400	2800	1850	3700

Table 7.1: Field of view calculations for progressive distances from camera (to nearest whole number)

For the purposes of this research project it was felt that this field of view would result in a high level of unwanted data as at the stable limits of the scanner, the projected stripe would fall well within these limits. Stretching the scanners to the limits often resulted in an instability of the scanning laser stripe, causing a flickering effect and a jumping of the stripe to random positions. This problem is discussed later.

A trimmed region within the field of view was decided upon of 1900mm on the horizontal by 1300mm on the vertical captured through the image processing system. This allowed a standard for image collection across the two image processing systems and enabled the images captured to be closer to the limits of the scanner range. Captured images were then stored in a standard 24 bit bitmap form measuring 630 pixels by 460 pixels. See figure 7.9.

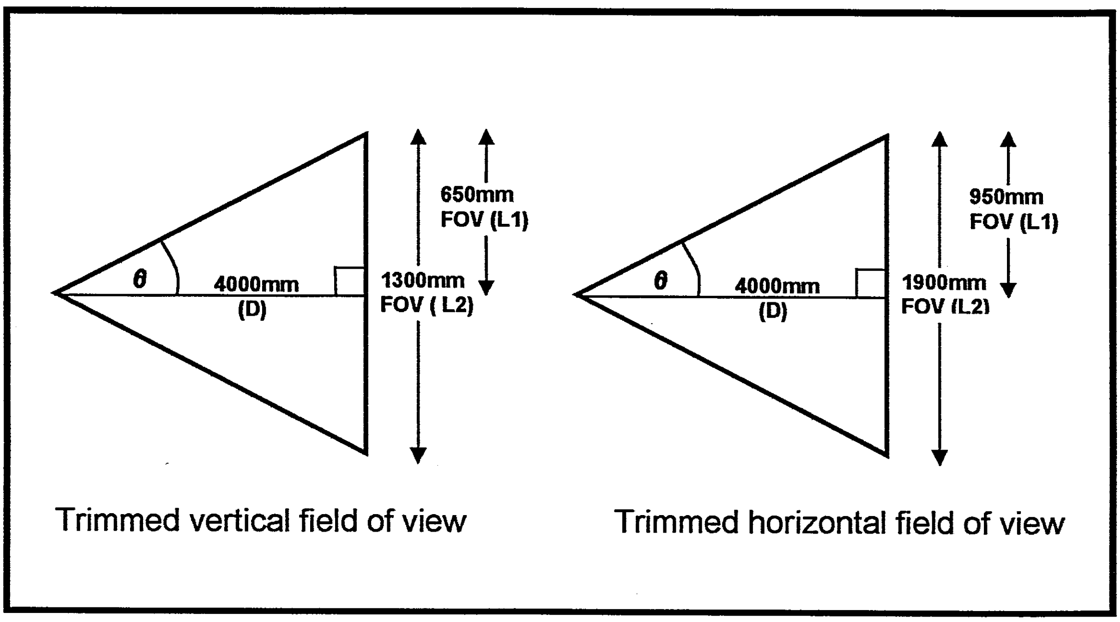


Figure 7.9: Trimmed vertical and horizontal field of view at 4m

From this a relative measurement for ***θ*** could be returned

$$\tan \theta = \frac{L1}{D}$$

Equation 7.2

Thus ***θ*** for the vertical = 9.23° from the norm and θ for the horizontal = 13.36° from the norm

Where ***D*** is the distance between target object and camera and θ is equal to 9.23° on the vertical and 13.36° on the horizontal, the length of the field of view can be extrapolated from the following equation;

$$FOV\ (L2) = 2\ (\tan\theta \times D)$$

Equation 7.3

Table 7.2 shows the calculated field of view length at progressive distances ***D*** from the camera to the nearest whole number;

Distance (*D*) mm	**Vertical FOV (*L1*) mm**	**Vertical FOV (*L2*) mm**	**Horizontal FOV (*L1*) mm**	**Horizontal FOV (*L2*) mm**
500	81	163	119	238
1000	163	325	238	475
1500	244	488	356	713
2000	325	650	475	950
2500	406	813	594	1188
3000	488	975	713	1425
3500	569	1138	831	1663
4000	650	1300	950	1900

Table 7.2: Field of view calculations for progressive distances from camera (to nearest whole number)

Thus the relationship between pixel spacing on an image of a target object and the range of a target object from the camera can therefore be calculated through the following equation;

$$\textit{Relative pixel spacing} = \frac{2(\tan\theta \times D)}{\textit{pixels displayed (h) or (v)}}$$

or;

$$\textit{Relative pixel spacing} = \frac{FOV\ (L2)}{\textit{pixels displayed (h) or (v)}}$$

EQUATION 7.3

Where ***h*** = horizontal pixels displayed on image and ***v*** = vertical pixels displayed

From this, pixel spacing relationships were found for increasing range from the camera and are shown in table 7.3 below.

Distance (*D*) mm	Vertical FOV (*L2*) mm	Vertical spacing mm	Horizontal FOV (*L2*) mm	Horizontal spacing
500	163	0.35	238	0.38
1000	325	0.71	475	0.75
1500	488	1.06	713	1.13
2000	650	1.41	950	1.51
2500	813	1.77	1188	1.89
3000	975	2.12	1425	2.26
3500	1138	2.47	1663	2.64
4000	1300	2.83	1900	3.02

Table 7.3: Relative pixel spacing (mm) for progressive distances from camera (to two decimal places)

Calibration of these results could be carried out by pixel density measurements taken across a target object of known size and at a known distance from the camera. This allowed a comparison with the theoretical data noted previously, to determine the accuracy of the system. A specific programme was written within Labview to perform this calibration. The operation screen for this is shown below in figure 7.10 and shows measurement of pixel density on the vertical axis. The barrel target is 470mm from base to collar and 325mm in diameter.

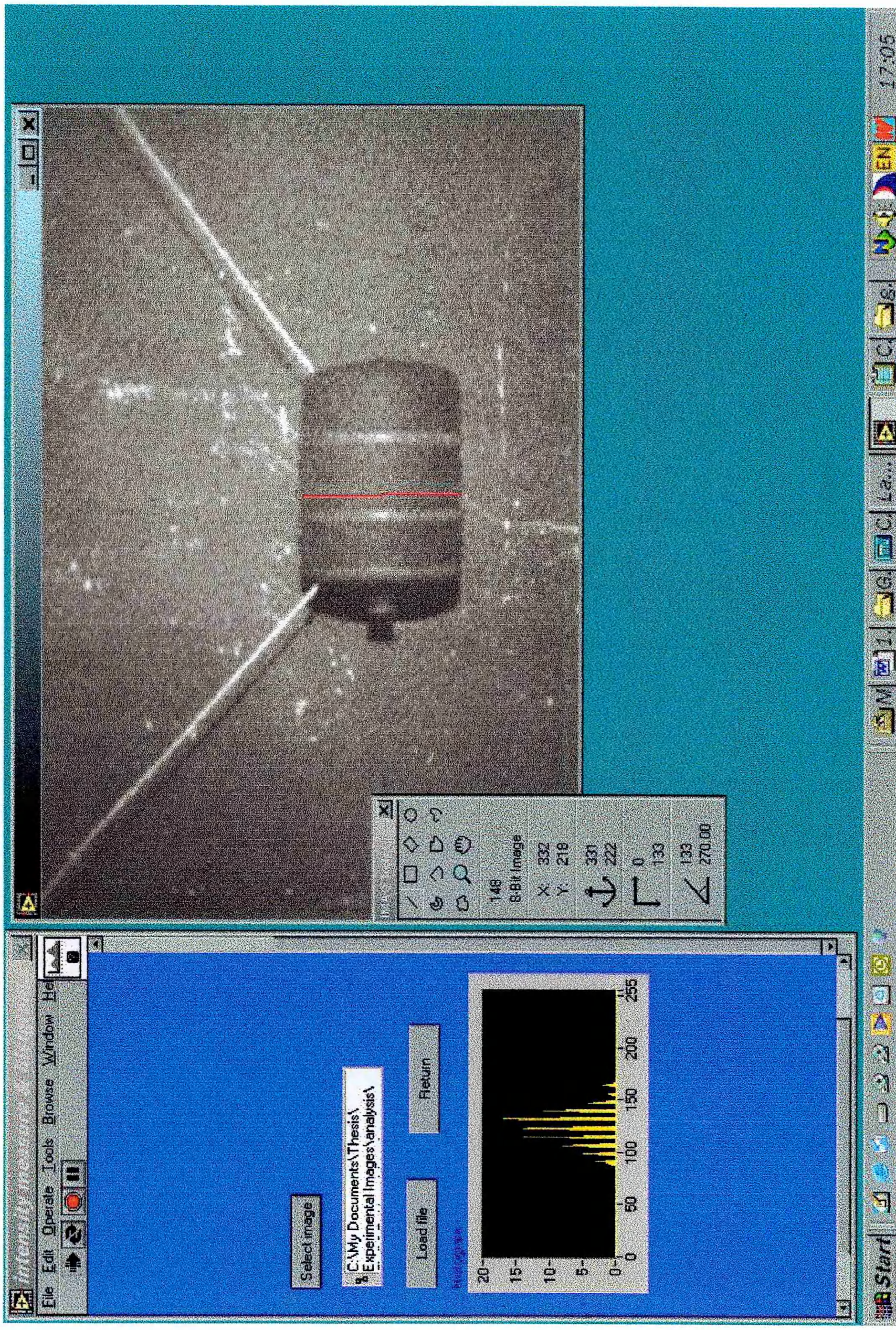


Figure 7.11: Image calibration algorithm, Operator Interface

Results were achieved for target positioned at a range of between 4m and 1.5m from the camera and are listed in table 7.4 below.

Range from camera	Vertical Axis			Horizontal axis		
	Number of pixels across target	Distance across target (mm)	mm per pixel	Number of pixels across target	Distance across target (mm)	mm per pixel
1500	291	325	1.12	412	470	1.14
2000	231	325	1.41	316	470	1.49
2500	180	325	1.81	231	470	2.00
3000	152	325	2.14	203	470	2.32
3500	133	325	2.44	179	470	2.63
4000	119	325	2.73	158	470	2.98

Table 7.4: Pixel density calibration results for direct measurements of target object

7.5 THE LASER SCANNING SYSTEM

The Adlas laser is positioned in the viewing window at an offset from the camera of 600mm. Two scanning units scan a laser stripe across the field of view of camera illuminating the target region progressively. The first scanning unit or 'stripe scanning unit' (SSU) as it will be referred to in this thesis, projected a vertical laser stripe, whilst the second 'Cross field scanning unit' (CFSU) scanned the stripe back and forth. The scanning range of the laser stripe has a direct relationship with the visual range demonstrated in figure 7.12.

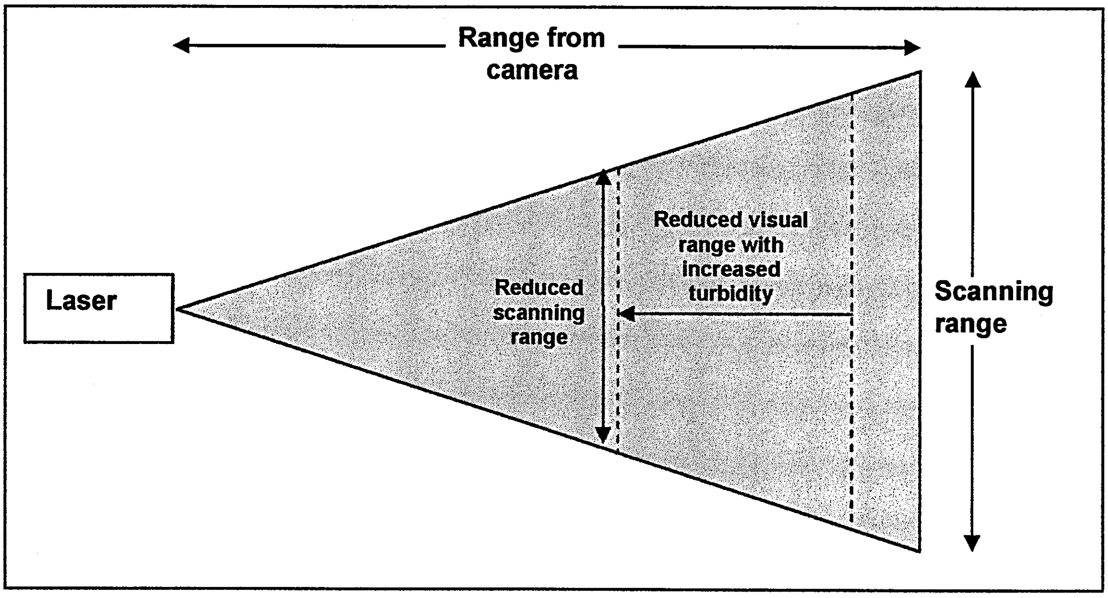


Figure 7.12: The relationship between scanning range and visual range

Within a highly turbid medium the visual range will be restricted and thus the scanning range will decrease. An important consideration in the testing of the imaging system is that the scanning limits of the laser should fall within the field of view of the images being received. This is required as a fully defined stripe is necessary for a full analysis.

The ideal position for the laser scan is dependent upon the range at which a target object is situated from the camera, with the centre point of the scanning range positioned in the centre of the field of view of the camera. This would maximise the scanning ability of the laser across the FOV. A level of control over the scanner direction is available to the operator through the offset dial on the scanner control unit, but as the offset is increased the range of the scan decreases as the scanners reach their stable limits.

This has ramifications on the separation between camera and laser as an increased offset position of the laser will require an increased offset through the scanner control unit particularly over extended ranges. A level of control of the offset between camera and laser is desirable as well as a directional control over direction of the laser. This would allow the system to be more reactional to altering conditions in the environment.

Within the limits of the 4m test tank and accepting a standard 600mm offset for the laser, limited primarily by the geometry of the viewing window, the system can be set to an optimum angle for a 4m range, positioning the centre of the laser scanning range to the right of the centre of the FOV of the camera. Through a simple trigonometrical calculation this optimum angle can be found at 8.5° from the norm. Referring to figure 7.13, this will give an equal range of scan to either side of the centre of field of view so that **A** to **B** = **C** to **D**.

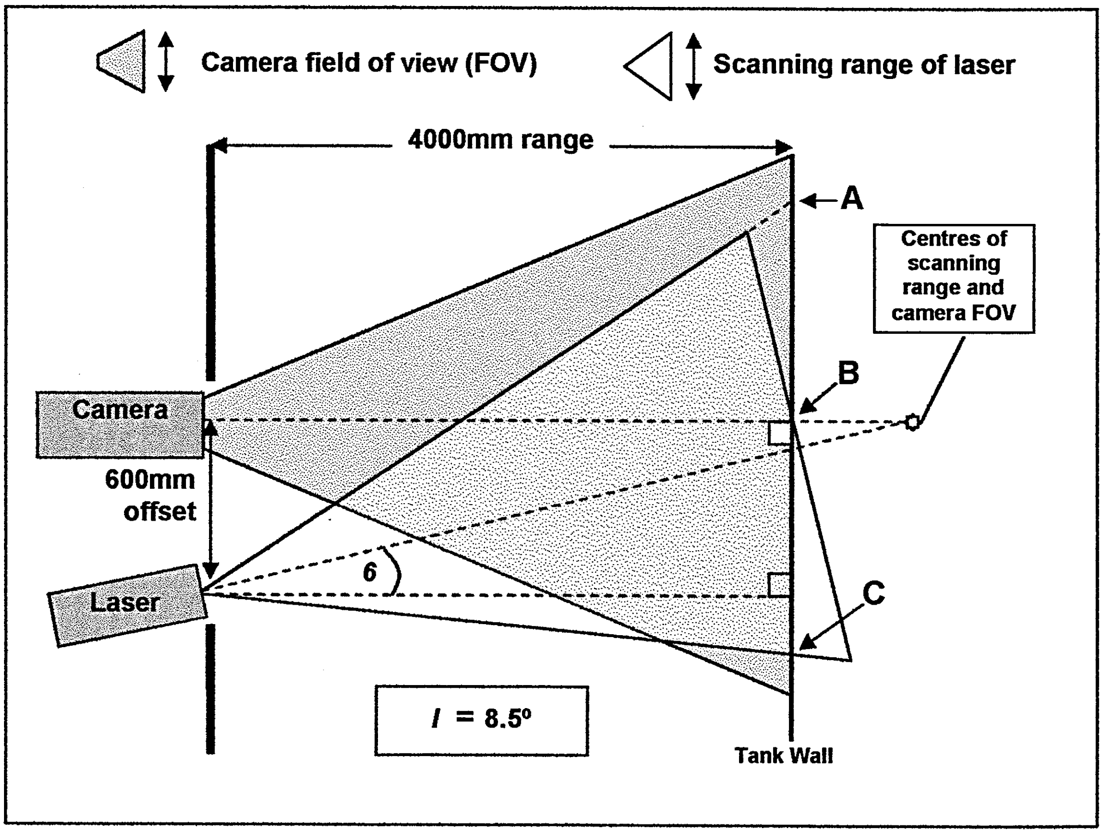


Figure 7.13: Optimal angle definition in the 4m test tank

The offsetting of the laser will result in a small difference of light intensity across the scanning range, a situation that is increased as the target object is moved closer to the camera as the angle at which the scan is made across the target increases Inversely though over greater ranges the alteration in intensity delivered across the target will reduce.

7.5.1 INSTABILITY OF THE LASER STRIPE SCANNERS

The instability encountered in the scanning system towards the limits of the laser scan could dramatically reduce the effectiveness of any image processing system, as a smooth scanning stripe is required. Examination of this problem attempted to define the restrictions of this behaviour but produced inconsistent results, indeed the extent of the problem seemed to alter with no particular pattern. The situation would often worsen though if the scanners were used over an extended time.

To remove the possibility of the occurrence of this problem it was decided to keep the scanning range well within its stable limits. In attempting to scan the target objects used for the purposes of this project, the size of the target objects used would offer minimal restrictions to the testing of any processing algorithms. Only when positioning objects at close range, < 1.5m would this restrict the ability of the scanners to project a stripe across the entire object in question.

7.5.2 LASER SCANNING SPEED

The production of the laser stripe on the vertical axis requires a scanning speed sufficient to produce an effective standing stripe. The required speed though increases as the speed of the cross field scan is increased. If the stripe scan is set too low and the cross field scan too high the effect produced is a dragged stripe. In other words the stripe will not appear truly vertical in a grabbed image.

The scanning speed of the cross field scanning unit predicts the rate at which the stripe will pass across the target region. In terms of the image processing of the stripes this is vital as it will alter the number of stripe grabs that can be collected in one pass of the target. Too few grabs and the image will not carry enough visual information to allow effective recognition of the object in real time.

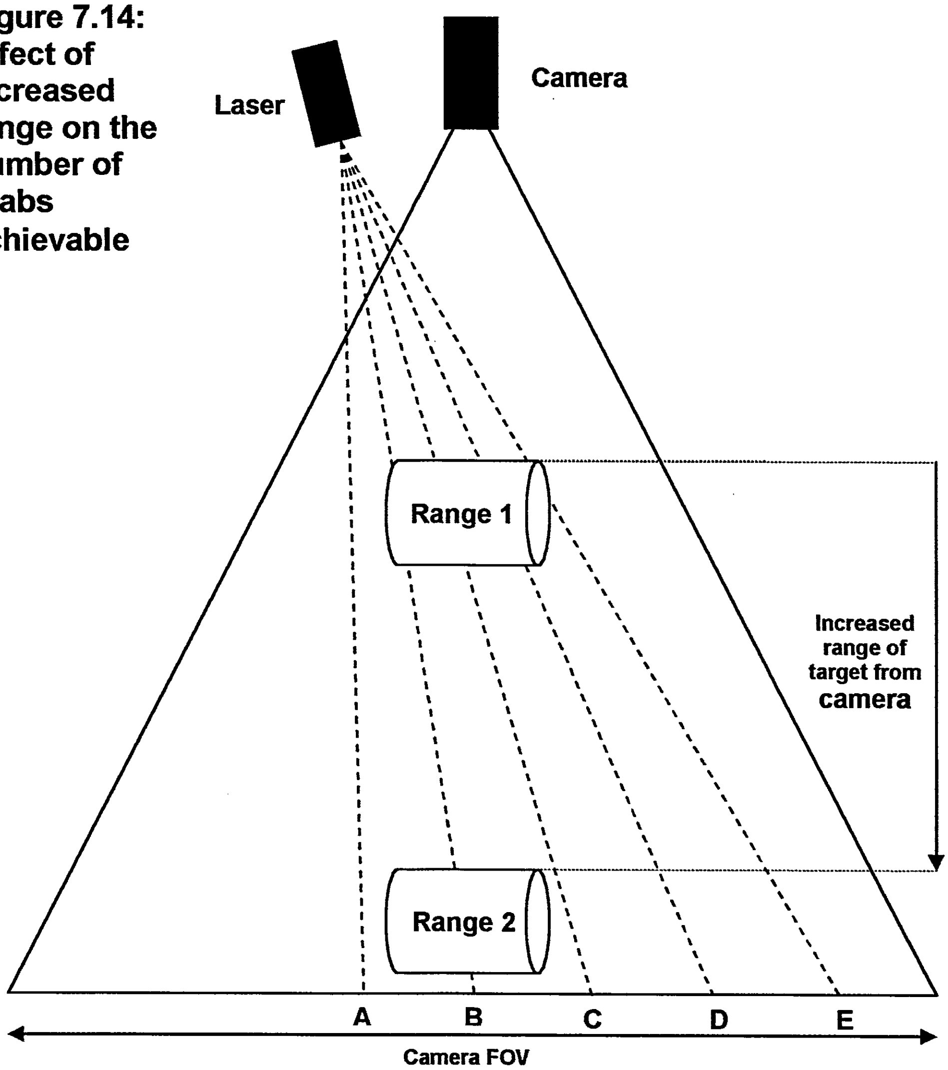
The speed of rate of grab through image processing is set by the processing speed of the algorithms used. This in tern is defined by the level of processing required to be carried out within the algorithm. So any algorithm must be optimised, ideally through simplicity but the effective processing of images can only be simplified so far, so the speed of cross field scanning must also be optimised to support the system.

In previous work carried out on the system, Spours [7.3] explored the relationship between cross field scanning (CFS) speed and the speed of successive grabs using a simple Vision Blox addition algorithm. Carrying out a series of tests he attempted to ascertain optimum CFS speeds for the algorithm. He deduced that a minimum CFU scanning speed had to be maintained to ensure a level of stripe individuality during an addition process. This was required to allow the processing system to identify the individual stripes for extraction.

Noting that the individuality of the stripe region reduced in conditions of higher turbidity when images in close proximity to other stripes, he incorporated a level of threshold control to the algorithm to lessen the effects of scattering on the images.

There is though a question of range that must be incorporated into this optimisation. Stripe grab separation will not alter over increased range but the number of grabbed stripes that emanate from the same target object will. Attempting to show this relationship between range and target based stripe grabs more clearly, figure 7.14 Shows the projected paths of 5 grabbed stripes **A** to **D**.

Figure 7.14: Effect of increased range on the number of grabs achievable



When attempting to construct an image of a target object over greater range, fewer grabs emanating from the target object will be achievable. From the diagram it can be seen that in range 1 the path of grabs B to E will allow visual information to be taken from the target object whilst in range 2 only the path of grabbed stripe B will produce visual information. The effects of this are to dramatically reduce the real time visual ability of the system over greater ranges.

The obvious answer to this range issue is to have a level of cross field scanning speed control built into the system which it is, but the conclusion that can be drawn from this is that optimisation of the cross field scanning speed is dependent upon range, and so must be flexible. This issue is an important one in the assessment of the system as a search tool.

7.5.3 LASER DIVERGENCE

As a laser light is projected through a medium its properties will alter and this is particularly so when the medium is water. The beam will show a tendency to increase in size or diverge, the extent to which is highly dependent upon the level of turbidity within the water column. Other factors that may have an effect on the laser path divergence are the characteristics of the surface of any objects placed in the path of the laser beam and any deviations in the laser characteristics from initial manufacturers quoted data [7.3].

With the projection of the laser stripes onto a target object, this behaviour could have a distinct effect on both analysis data and the determination of cross field scanning speed. So it is important to explore more closely the relationships involved in the divergence of the laser stripe.

From the manufacturers data the Adlas 315 Nd:Yag has a beam diameter of 0.32mm with a divergence of 2.2 milliradians.

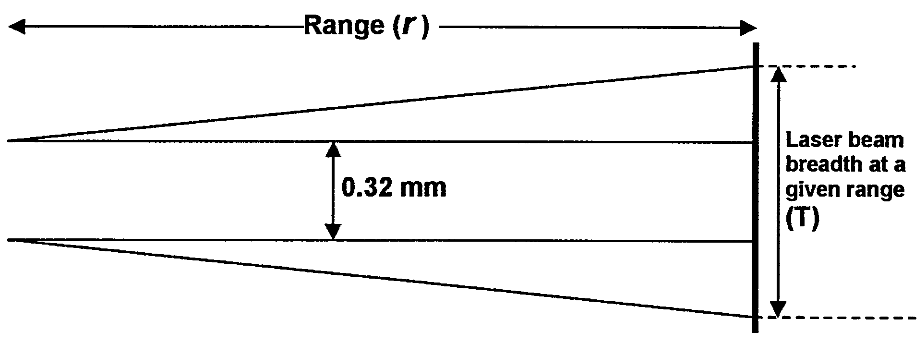


Figure 7.15: Laser beam divergence

Figure 7.15 equates the manufacturers' divergence data to the breadth of the laser stripe (**T**) at a given range (**r**). To calculate this divergence at a given range the following equation applies;

$$T = r\,(2.2 \times 10^{-3})$$

Where; r = 4000mm.

$$T = 0.0022 \times 4000 = 8.8mm$$

From this a calculation of theoretical laser divergence across the barrel target in air, can be drawn for ranges from the camera. The barrel target is 470mm from base to collar. Calculated divergence ranges in air are show in table 7.5.

Range from camera mm	Laser angle range across target (right to left) °	Laser range across target (right to left) mm	Diameter range across target (right to left) mm
1500	21.02 - 22.57	1606.93 - 1624.41	3.54 - 3.57
2000	16.08 - 17.32	2081.43 - 2094.99	4.58 - 4.61
2500	12.99 - 14.00	2565.66 - 2576.53	5.64 - 5.67
3000	10.88 - 11.74	3054.91 - 3064.10	6.72 - 6.74
3500	9.35 - 10.10	3547.13 - 3555.09	7.80 - 7.82
4000	8.20 - 8.86	4041.32 - 4048.31	8.89 - 8.91

Table 7.5: Theoretical ranges of beam divergence across the length of target barrel (in air).

It should be noted that these theoretical divergence ranges only apply to the centre of the projected stripe, as the divergence will increase slightly as the stripe scanner moves away from the centre to the extremes of the stripe.

Previous testing carried out on the system by Abercrombie [7.4] explored the divergence properties of the Adlas laser, conducting tests on the beam diameter over a range of 8m in air, clear water and turbid water. Results noted that over a series of four tests in clear water, an average beam diameter at 8m of 24mm was attained. Equating this to 4m a divergence of 0.00296 radians or 2.96 milliradians was seen, resulting in a beam diameter of 11.84mm. An increase in divergence was thus seen from the manufacturer's data.

The results of tests carried out in a turbid medium, produced results showing a reduction in beam diameter and noted that this result is the opposite of that expected. Abercrombie suggests that this was due to the raised attenuation of the beam as it was projected through increasingly turbid conditions. The position is that as turbidity is added to the medium the definition of the beam becomes progressively harder to define and becomes more a factor of scattering than direct beam. Beam divergence is thus almost impossible to impossible to define against the level of turbidity experienced this conforms to the point made by Spours that divergence is affected by the level of turbidity experienced and the characteristics of the surface of any objects or scattering agent placed in the path of the laser beam.

The choice of a green laser source provides the system with the optimum colour for transmission through water, particularly in coastal and surf zone regions. Unfortunately the fundamentals of laser physics do not support its use. The use of shorter wavelengths results in a dramatic reduction in the ratio of stimulated emission to spontaneous emission in the underwater environment. This means that lasers sources in the blue/green range of the spectrum are relatively inefficient in this medium. [7.5]

8 ALGORITHM DEVELOPMENT

The Cranfield laser stripe imaging system projects a scanning stripe through the water column until it is reflected by a target object situated in its path. In reality, due to particles within the water column, light will be scattered throughout the medium. This creates noise on the received image and thus target clarity is greatly reduced with increased turbidity.

In the use of image processing to extract a final image of the target it is important to realise that the desired extraction is not the target, but the stripe, and it is the processing of the extracted stripes that will produce the image of the target region. Thus it is the isolation of the stripe illumination from the noise that is the important factor.

Figure 8.1, **A** to **F** shows the consequence of increased turbidity on underwater imaging of the laser stripe and a black and white striped target. Turbidity is provided by adding bentonite increments of 25g.

These images show graphically, the problem that is faced in achieving image quality in high turbidity. What can be seen though is the intensity of the laser stripe that is projected against the target and its ability to define the contrast between the black and white stripes on the target, even as turbidity is increased substantially. The difficulty arises in definition of the laser stripe as turbidity is raised.

For the effective compilation of the final image, it is important that the algorithm is able to define the stripe as tightly as possible but as can be seen from the images, as the turbidity is increased the edge of the stripe becomes progressively less defined. If a stripe is extracted without truly defining the image the result is the transfer of a great deal of scattering information of unknown origin.

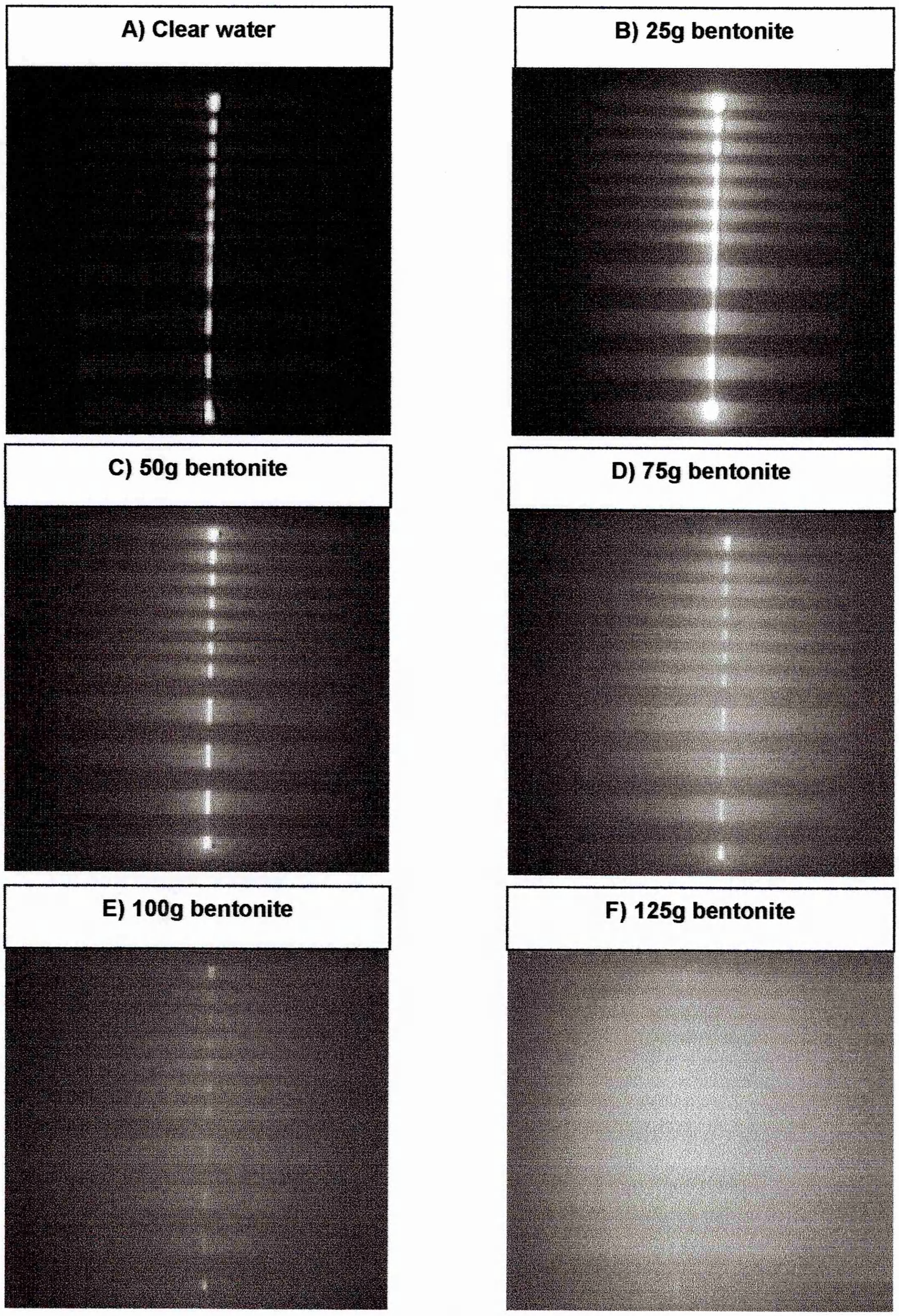


Figure 8.1: Effects of increased turbidity on the laser stripe

By measuring the intensities along the stripes it is possible to display the contrast reduction as turbidity and therefore scattering is increased. Figure 8.2 shows intensity graphs along selected stripes A, C, D, F taken from figure 8.1.

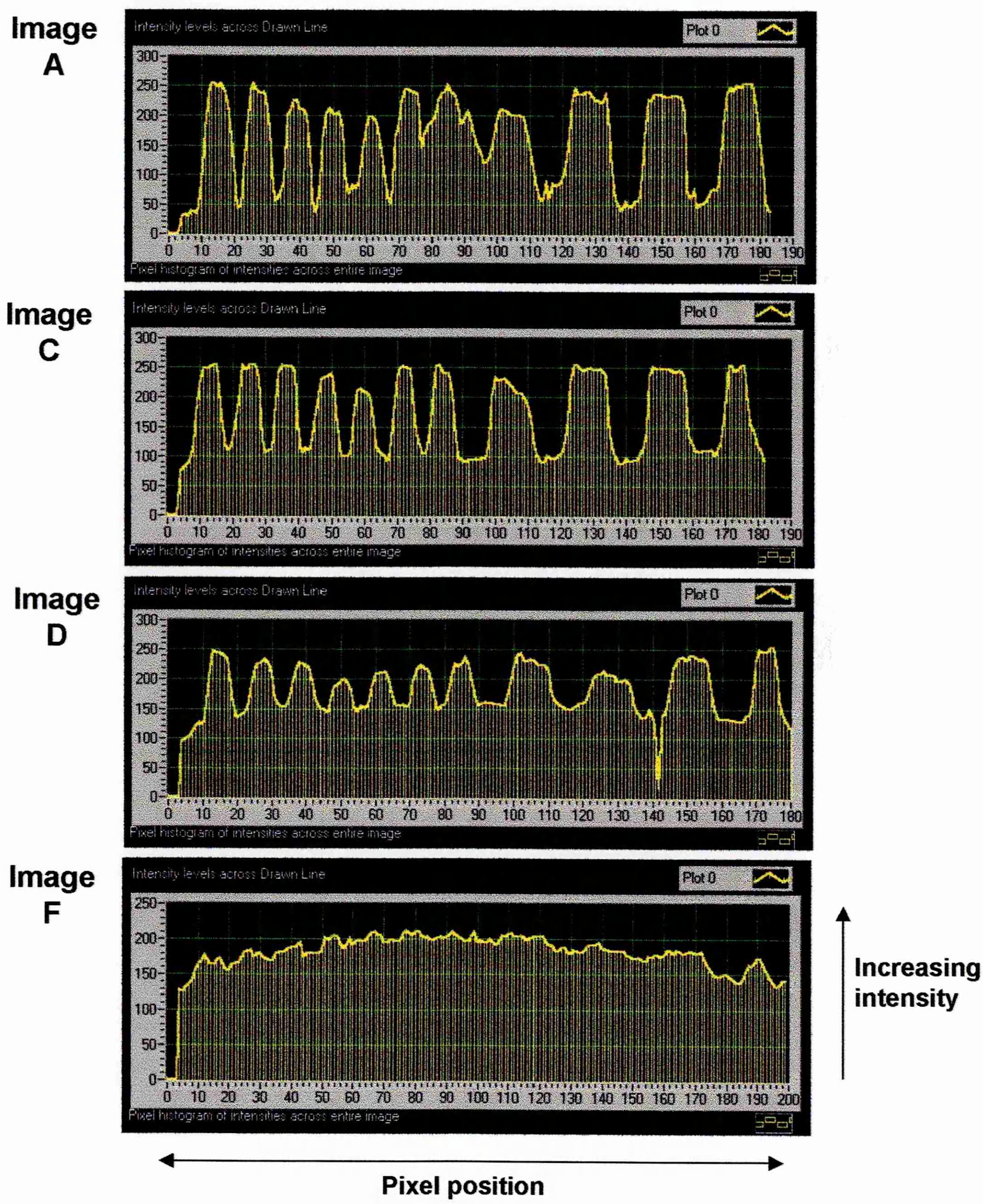


Figure 8.2: Intensity graphs for images A,C,D,F taken from figure 8.1

Contrast between stripe information on the white regions of the target, shown at the peaks of the graphs can be compared to the black regions indicated by the troughs. Stripe A shows clearly defined contrast alterations across the stripe. This is gradually eroded as turbidity is increased until contrast is virtually unrecognisable over stripe F. Stripe definition is progressively reduced and therefore stripe isolation is made significantly more problematic. What can also be seen is that this is not only an issue of generally increasing intensities across the stripe but that the intensity of the stripe itself is being reduced thus the peaks and troughs are converging

The second aspect to be considered is the cross field scanning (CFS) of the laser stripe. As discussed in the previous chapter, the correct speed of the CFS is vital for the effective and recognisable capture of an image of the target in real time. For the optimisation of the process this must be combined with the optimisation of the processing speed of the algorithm between successive grabs of the laser stripe. Thus processing time should be kept to a minimum.

8.1 IMAGE PROCESSING SOFTWARE

Before the development of the image processing techniques required to work within the system could commence, it was essential to select an appropriate image processing package. There are several systems available to the developer that could have been considered for this project including HL Image ++, Ramases, Visilog and Global Lab, Some previous work on the system had been carried out using Global Lab but more extensively with the use of Vision Blox 2.1. This package operates using Visual Basic 4.0 programming language and offered itself as an appropriate starting place for the development of the processing techniques for the laser imaging system.

8.1.1 ALGORITHM DEVELOPMENT IN VISION BLOX

The Vision Blox package presents a front screen operating interface, allowing specific commands to be entered or boundaries altered by the operator. A main algorithm is written and run within the system that can react to the instigation or alterations of sub-programming scripts. These sub-programming scripts can be used to operate various processes, to enhance, alter or extract information from the images fed into the system.

Vision Blox has certain integral processes included in the system that are capable of stripe isolation. Each of these are made available on the interface by means of a unique icon, and sub-programming of each tool can either define its properties or create a range of options to the operator for its use. These tools are:

-Blobs Tool: The conducting of a connectivity analysis on an inspection image, displaying the results in the form of an overlay on the display window. This connectivity analysis performs a segmentation of the image into regions of similar intensity, within limits defined by the operator. The name Blobs tool refers to the appearance of the defined regions, as a colour coding can be applied to the regions creating the appearance of a coloured blob on the display window.

The Blob process is carried out in several stages beginning with image binarisation to produce a black and white image. This stage is intended to promote features of the image that are of most interest to the foreground with the boundaries of this interest either being determined automatically or manually. After this stage, the image is passed through the connectivity analysis, grouping pixels into regions of similar or equal intensity. The number of these groups can also be defined by the operator to limit the process. In the final stage blobs are sorted with the use of specified criteria such as size.

A wide a range of analysis information can be extracted fro the tool such as blob width, pixel numbers and centre of gravity. An area of a blob can be used to define the position and dimensions of a region of interest or ROI, allowing specific operations to be carried out in this region alone whilst leaving the rest of the inspection image unaffected.

-**Edge Tool:** As its name suggests the edge tool can be used to locate edges within a predefined region of interest on the inspection image. To define an edge, the tool requires training through the use of a selected edge to compile a statistical model of that edge. It then utilises three characteristics; contrast, position and polarity, to compare any possible edge found within the region of interest, to the model.

Contrast is used to compare regions of pixel intensity change against the edge model. Position uses the mid points between paired edges and then comparing its position within the region of interest to the model. Finally polarity compares regions of light to dark found within possible edges to the model. The training of the edge tool can include a number of examples and can be readily updated by the operator.

-Caliper Tool: The Caliper tool is a more defined version of the edge tool, which is capable of distinguishing pairs of edges within the predefined region of interest. Once again the system requires a level of training to construct a statistical model of an edge pair and identification of possible edge pairs can then be carried out through comparison.

The Caliper tool uses the same characteristics to create its model but with the addition of separation which it uses to compare the separation between possible edge pairs to the model.

Each of these tools use a level of pixel intensity analysis to define their parameters. Indeed, pixel intensity is the primary characteristic of digital imaging. As discussed previously each pixel is consigned a value between 0 and 255 and it is this value that defines its intensity. 0 equating to black and 255 to white, with all values in between defining a different greyscale shade, enabling a recognisable image to be constructed from a matrix of these pixels.

Taking that a laser stripe appears on an inspection image as a large elongated grouping of pixels with relatively equal intensities, then noise will appear as small groups of pixels with increasingly lower intensity values the further away from the stripe they are found, Then it should be possible to utilise a threshold restriction to cut away much of this unwanted noise. This threshold restriction can be used in hand with the processing tools described above identify the stripe regions shown on the inspection image.

The difficulties involved in the removal of backscattered light from underwater images have tried and tested image processing developers. These difficulties lie not just in the presence of the backscatter but in the nature of the images that the backscatter produces. When backscattering occurs through the laser stripe system many of the pixel intensity values being extracted with the stripe, do not actually contain visual information from that region of the target due to scattering. It is also not true though, that scattered light occurring around the immediate limits of the stripe does not hold any visual information that may be useful as forward scattered light may offer a low level of target illumination.. In reality even in a highly turbid medium much of the information required to compile the image is contained in the image; it is just in the wrong place. But in the absence of detailed pixel level knowledge of a target object; sorting useful pixel information from pure noise and placing them in the correct positions, is an impossible jigsaw.

Inversely, in a perfect situation the imaging system will be visualising through a completely non-scattering environment. But removing all particles and objects from the path of the laser would result in a black image on the operators screen. If a target object would be placed in the path of the laser then this would be visualised in greyscale, even if the target object were black. Thus the information that can be extracted from a laser stripe is purely an interpretation of the target object in a greyscale form. This then leads us to the question; what visual information should we be looking to extract from images captured through the system?

Laser stripes can firstly identify the presence of an object their path. Secondly the stripe shape and the intensity of its reflection can identify much of the geometry of the target object and thirdly the system can identify differences in the reflective properties of the surface of the object through a greyscale range. The development of the image processing techniques have targeted the collection and enhancement of this visual information to offer the operator the best possible interpretation of a target object and to aid in its recognition.

Finally in defining the success of this system as a recognition tool it is important to realise to what level we can define an unknown object in a turbid medium. Identification of an object is a relative subject though, that relies not only upon the success of the underwater vision system, but also upon the knowledge and experience of the operator. For example; if in the course of this thesis it is claimed that an object is recognisable in a particular level of turbidity, at a particular range, it can only be correct for those who know what the object is. Those who are not previously aware of the identity of the object could suggest that the object is not recognisable at the stated ranges. So the use of the system in the field could result in attempting to recognise an unknown object that may not be identifiable to the operator at the ranges suggested in the laboratory.

To aid in the development of the processing techniques and the analysis of the resultant images, the algorithms were constructed to allow not just the input of life images but also to call up previously stored still images. This would enable the examination of the processing under certain controlled conditions. To further support this each of the integral sections of the processing could be enabled individually.

The development of the algorithms within this image processing package began with certain tried and tested building blocks conceived early on in the development of the system. Tetlow's [(8.1)] work in the early 90's explored the use of thresholding and edge finding tools within the Ramases III image processing package. He noted that thresholding at too higher level would result in the loss of visual information offered in pixel intensities below that threshold. This is the critical restriction of the thresholding technique. It is a distinct cut off point a very vague environment.

With respect to edge finding, Tetlow noted that the direct use of the tool was limited by the system requiring the identification of both edges of the stripe and being able to differentiate between the two. To allow the correct information to be extracted a manipulation of the system would be required. A third technique explored by Tetlow was that of Temporal Differencing.

8.1.1.1 Temporal Differencing

If we can imagine two images are grabbed from the target with progressive movement of the laser stripe. It is possible using image processing to subtract the first stripe from the second and in doing so remove a large level of unwanted backscatter from the image. Taking the illustration in figure 8.3 as an example, assuming the beam paths are essentially the same, theoretically this would leave only the stripe information in the resultant image.

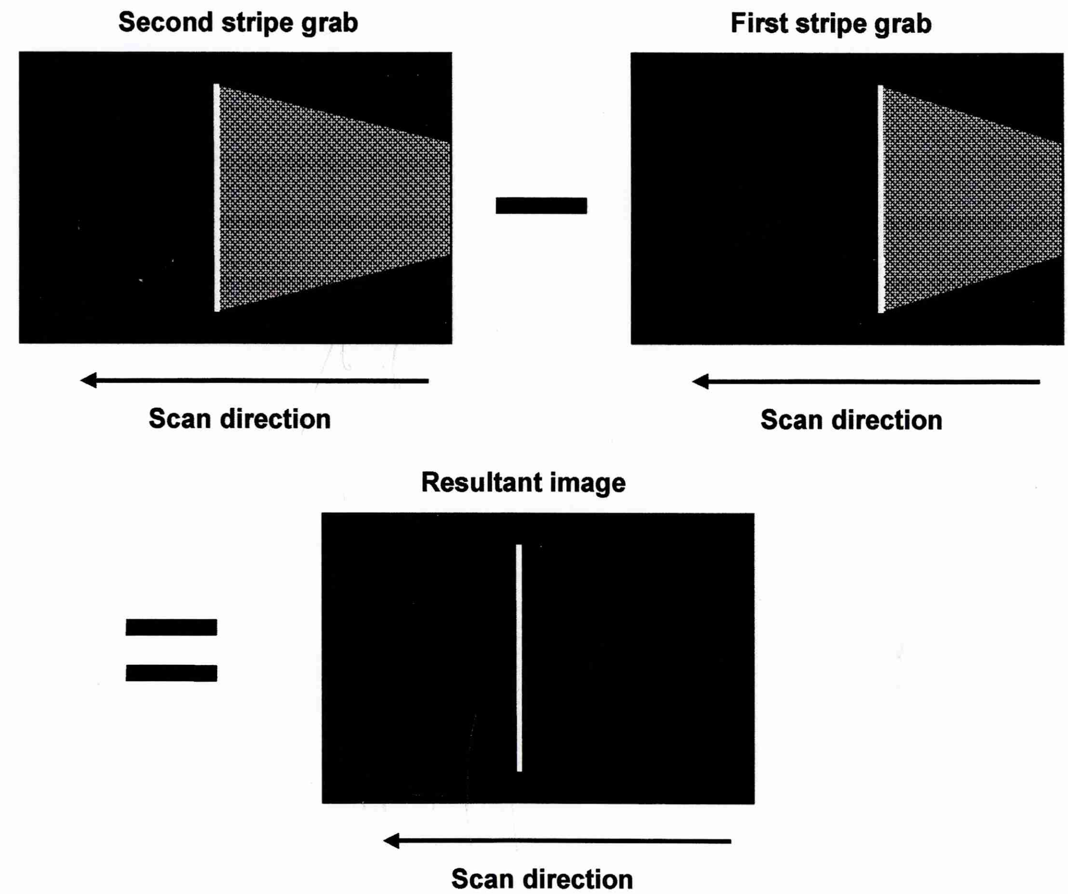


Figure 8.3: Subtraction of pregessive stripe grabs

Analysis of this process lead Tetlow to conclude that although the process did not produce images without the presence of noise, the overall image contrast is increased. Through the inclusion of this process immediately after the grabbing of the stripe images it is then possible to greatly increase the contrast of the stripe region against the rest of the image. In doing so the isolation of the stripe is made all the more viable. It was decided then that this process should be included as an initial image preparation procedure within the algorithms. Figure 8.4 shows this process in the form of a flow diagram.

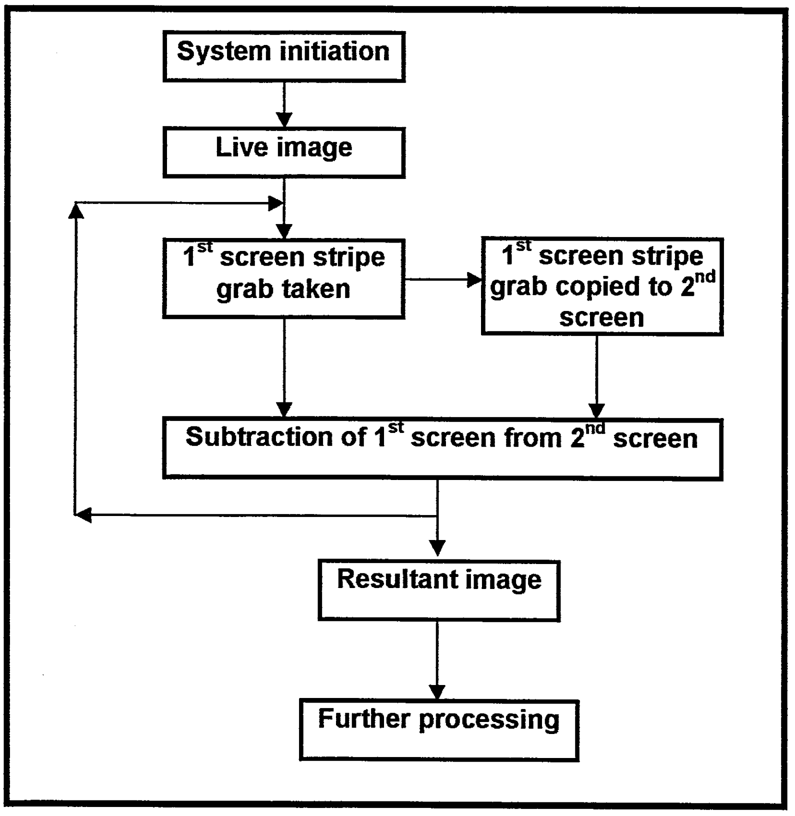


Figure 8.4: Flow diagram for subtraction process

The next stage to include in the algorithm was that of stripe isolation and algorithms were written that included the Blob, Edge and Caliper tools. Inside the resultant image a region of interest (ROI) is set within the limits of which the selected tool is required to inspect the visual information.

8.1.1.2 Regions of interest

The uses of regions of interest are primarily to define specific coordinates within an inspection image, within which processing tools are to operate. This feature can be used to speed up processing time across images by restricting the required operating ranges to those in which the operator knows that the information is most likely to fall. Regions of interest can be defined in certain preset shapes such as squares, circles or rectangles and can allow the operator to relocate all the visual information held within its boundaries to further inspection windows.

8.1.1.3 Isolation tool inclusion

It was possible to include each of the selected isolation tools within one algorithm allowing the direct and virtually instant comparison of their effectiveness. The success of the isolation could be judged by the tools ability to set a further rectangular region of interest (ROI) around the stripe and the ROI's accommodation of the stripe within its boundaries. It is this second region of interest which defines the area of the stripe image to be extracted for the compilation of the composite image.

The control of the blob tool was based on a threshold level that could be adjusted by the operator and set to best suit the altering turbidity levels. Limiting the number of blob regions to one, would identify the largest region of pixels within the set threshold range which in theory should be the stripe. Figure 8.5 shows a Vision Blox operation interface with the inclusion of Blob, Edge and Caliper Tool controls.

This interface offers two inspection images the left hand image offers the operator a view of the image after the stripe subtraction process is carried out. Two rectangular regions of interest are seen on this image. The green ROI or 'Editable shape' defines the reduced area in which the isolation tool is required to inspect the image and is predefined in the programming; the red is the 'floating' ROI that the isolation tool will set around the region of the stripe. The position of this ROI will alter in response analysis data offered by the particular isolation tool in question, setting the centre of the ROI to the centre of gravity of the stripe.

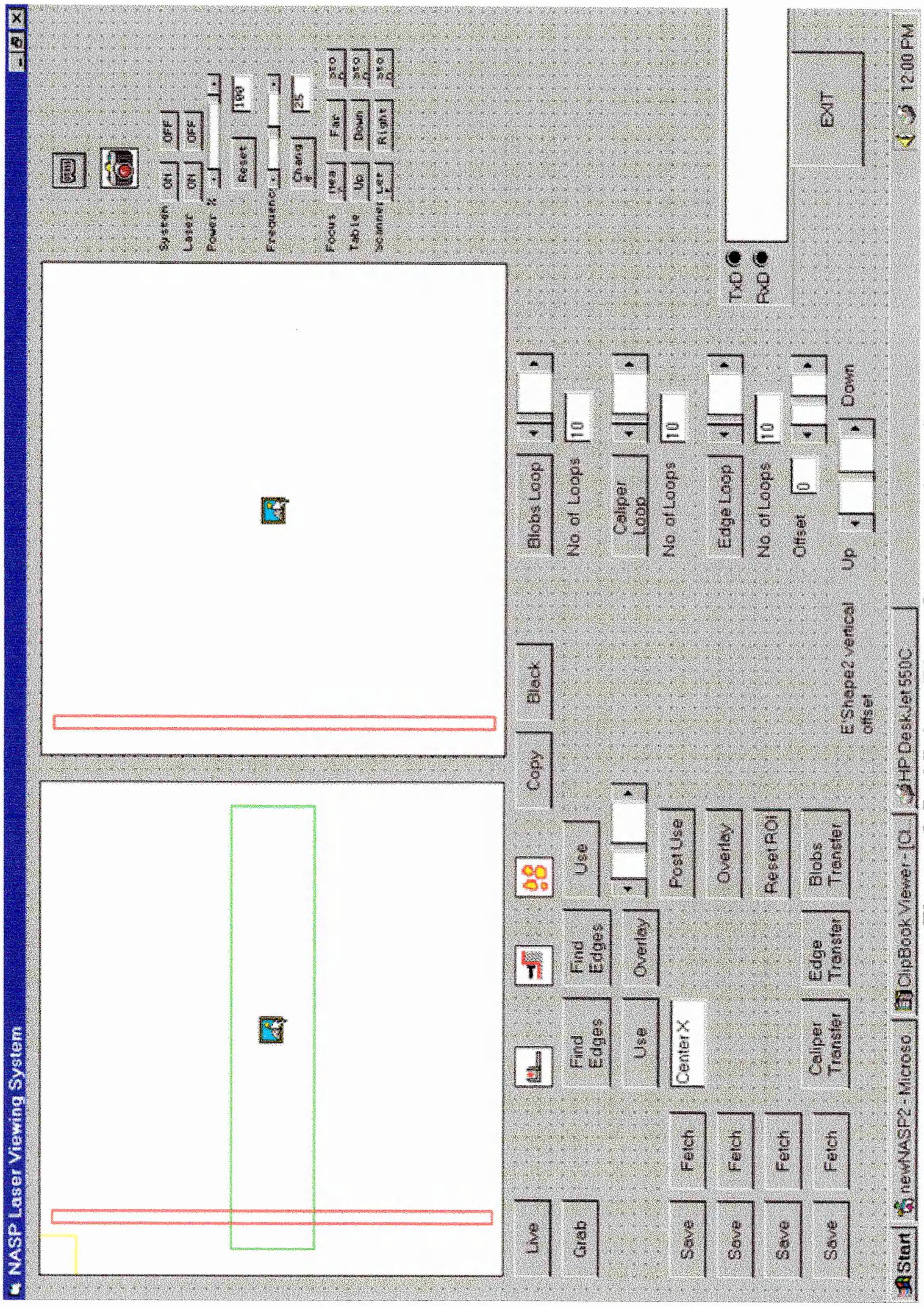


Figure 8.5: Vision Blox, Operator interface

All information that falls within this floating ROI will be transferred to the ROI positioned in the second inspection image. This second floating ROI will precisely mimic the behaviour of the first positioning the extracted information in the correct orientation. Successive stripe extractions will then build a cumulative of the target area.

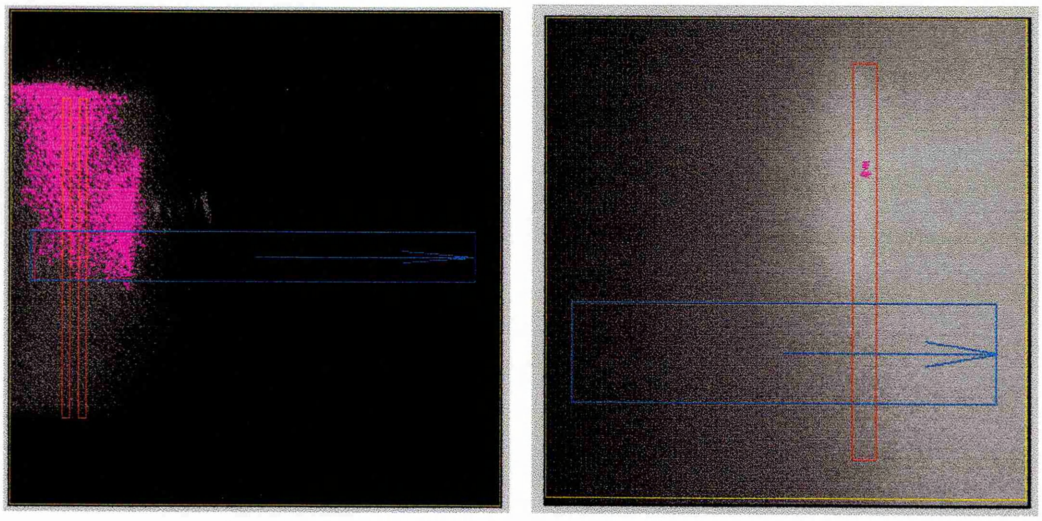
8.1.1.4 Assessment of Isolation tool performance

Blob tool

The assessment of the blob tool took on three stages as the tool was altered in reaction to test results. Tests were conducted against the wall of the test tank at a 4m range in clear water and a range of turbidities.

The initial set up of the blob tool involved a floating rectangular ROI of preset height and width and the ability of the blob tool to isolate the stripe in clear water conditions proved very effective. The floating ROI followed the stripe correctly and transferred the specified information efficiently. The preset dimensions of the region of interest though provided to flexibility and in the tests were larger than the stripes being analysed resulting in excess information being transferred to the cumulative image.

Tests carried out in higher turbidity levels revealed the limitations of thresholding techniques referred to by Tetlow [8.1]. With a wide threshold range set on the Blob tool the density of the scattering medium produced a large and irregular isolation region loosely orientated to the area of the stripe. With the floating ROI seeking the centre of gravity of the blob region this often resulted in it being set in the wrong position and so extracting visual information that did not include the stripe. This effect is shown in figure 8.6 below The Narrowing of the threshold range resulted in the loss of too much visual information



Blob tool with wide threshold range

Blob tool with narrow threshold range

Figure 8.6: Blobs tool control. Setting the right threshold?

It was realised that instead of presetting the size of the floating region of interest, its dimensions would have to alter in response to the dimensions of the isolated region. An alteration to the programme was made matching the dimensions of the ROI to the extreme limits of the stripe thus ensuring a 'snug' fit. This process performed well under testing in clear water trials but it was noticed however that due to a non uniformity in the geometry of the stripe an excess in the ROI was formed and so allowed a level of non stripe information to be carried through. This situation is illustrated in figure 8.7.

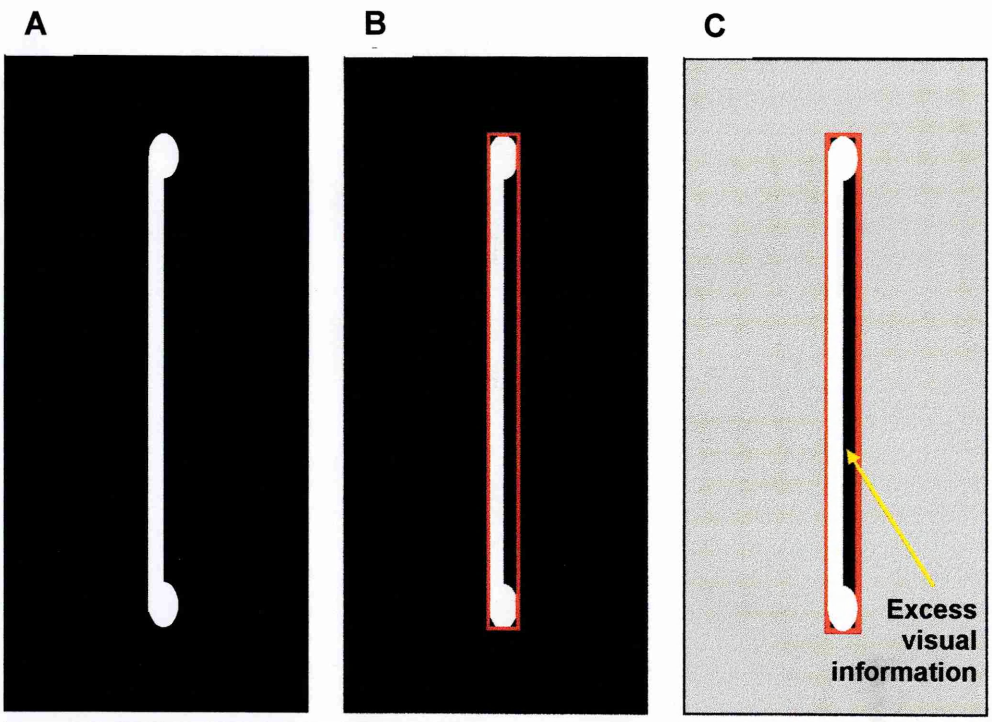


Figure 8.7: Effects of irregular stripe features on region of interest extraction

In illustration **A** the projected stripe geometry is not uniform, thus the measured width of the stripe is larger than the width found at the centre of the stripe resulting in a larger than required region of interest shown at **B** and so failing to fit uniformly leaving. The extracted visual information then once again carries an excess of visual information to the cumulative image, shown in **C**.

The laser stripe projection has a tendency to show a divergence at its extremes which defines the points at which the scan direction changes. This effect can be seen in figure 8.8, and is due to primarily to an increase in intensity of the beam as the scan slows prior to a change in direction. This effect can also be seen within the scanning beam as its projects through a turbid medium. The orientation of this divergence is dependent upon the direction of the cross field scan (CFS) being always situated on the trailing edge and will elongate at greater CFS speeds.

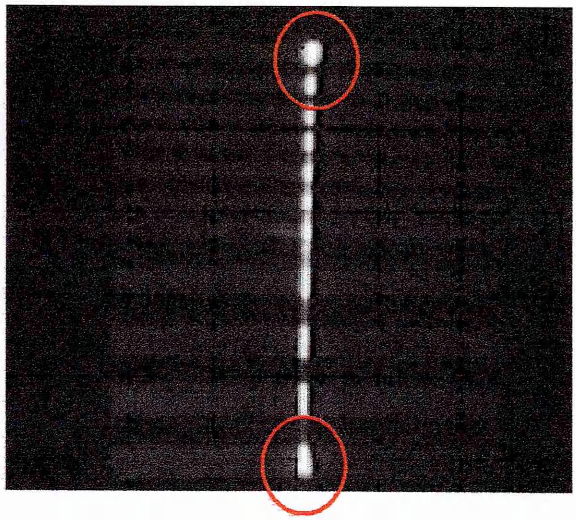


Figure 8.8: Divergence of the stripe at the limits of the stripe scan

This geometry of the stripe creates problems for a system that can only define regions of interest in certain preset geometric shapes. To perform this operation correctly an ability to define an irregular ROI capable of contouring the isolated region, would be required. An option that was not available through Vision Blox.

The stripe though is still basically an elongated rectangle, therefore to enable the region of interest to contour as much of the stripe as possible, A method was devised to allow the ROI to ignore the incongruities experienced in the geometry of the stripe. Vision Blox was capable of returning a range of properties for a region isolated through a connectivity analysis, so as well as maximum ***x*** and ***y*** values, minimum values could also be gained. Using these minimum values allowed the inspection area of the stripe to be trimmed enabling the floating region of interest to focus onto the minimum dimensions of the stripe.

First the minimum **y** value was used to trim the stripe length. The reason for this being, that a stripe with rounded ends would return a very small minimum value for its width ***x***, incomparable with the width of the main body of the stripe. Transferring this minimum ***y*** value into coordinates then gave a pixel length and position for the trimmed inspection as defined the length of the floating ROI. The minimum value for width ***x*** could then be read within this trimmed region to define the width of the floating region of interest. Figure 8.9 illustrates the process

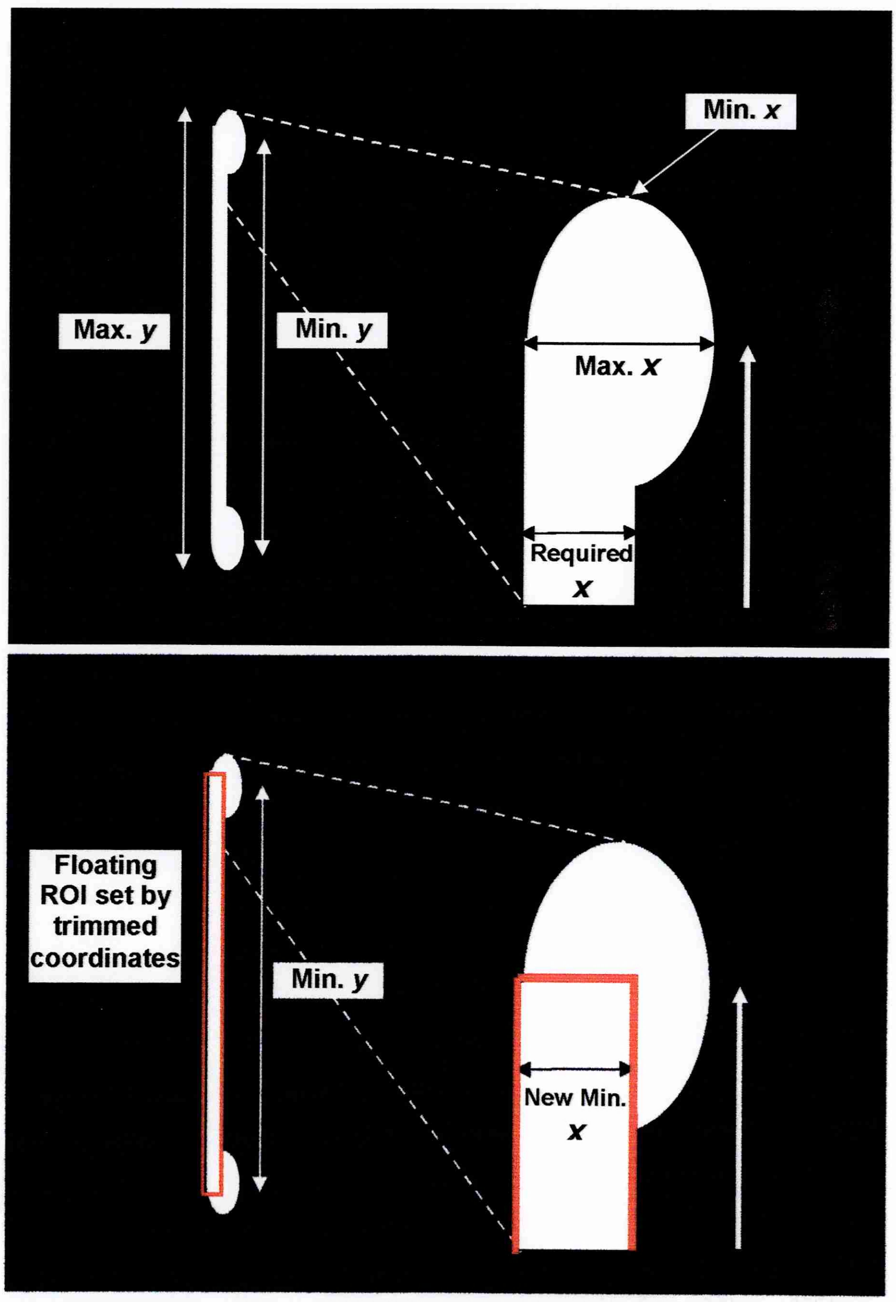


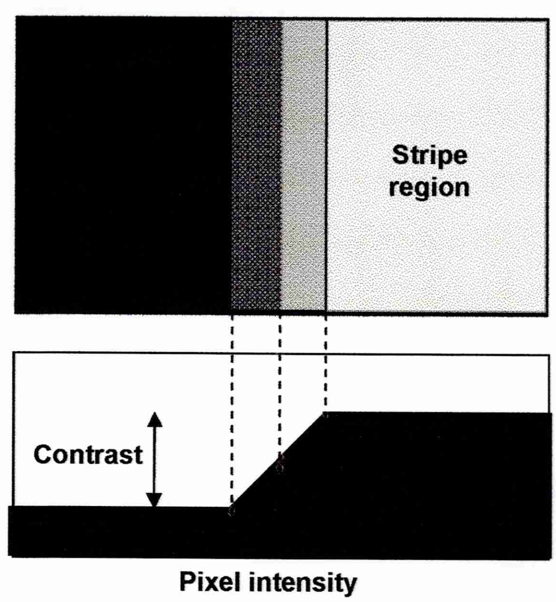
Figure 8.9: Trimming the stripe inspection region to tighten the ROI fit

In testing this trimming method worked very effectively in lower turbidity levels setting the region of interest correctly within the boundaries of the stripe. The transfer to the cumulative window now included predominately stripe information with the minimum of excess. The disadvantages of this technique though were that in higher turbidities the obtained values for minimum ***x*** and ***y*** became less defined, leading to altering stripe widths. Further the increased complexity of the isolation process reduced the number of stripe grabs achievable per scan, noticeably.

Edge Tool

Unlike the Blob tool, the Edge tool required a pre-training to enable possible edges to be compared to a statistical model. The tool must also be linked to the editable shape in which it must work so a definition of the region of interest is required and the tool must be trained within the editable image. Primary identification of an edge is by contrast change illustrated in figure 8.10, but a contrast weight can be applied to the tool to define the importance placed on the match between the contrast and the relative matching through other features of the edge. High weight values place high importance on contrast whilst low values place a lower emphasis on this characteristic. A polarity setting for the edge tool allows the tool to define the edge to be sought and is set during training

Figure 8.10: Identification of an edge



Once again this system was tested in conditions ranging from clear water to high turbidity to allow a full assessment of the tool. The difficulty in the use of the tool is that it effectively only find one parameter of the stripe; that is one edge. From this the floating region of interest must be set. Initial settings of the tool set the ROI centre to the centre point of the identified edge. So the system already had a level of offset from the stripe built into it. Naturally this resulted in the carrying over of excess information during the extract process.

Whilst the system operated as expected in lower turbidities, the definition of the stripe caused difficulties in identification of the stripe edge and resulted in the ROI losing the stripe completely. Despite the clear limitations of this technique an attempt was made to make the process more flexible both to improve the stability of the process and to improve the positioning of the ROI around the stripe.

Attempts were made to include an automatic tolerance in the process that could accept a less defined edge but failed to improve its performance. Progress was made though in the defining of the position of the region of interest. The dominant polarity is decided during training so the algorithm was given an offset level, to adjust the position of the ROI. If the dominant polarity was to the left of the stripe then the ROI would be offset to the right and visa versa. This was firstly built into the algorithm and then offered as an option on the operation interface by the entering of an offset value by the operator.

This development offered improved ROI, positioning but with the limited data available from the edge tool the manipulation of the process to tighten the dimensions of the ROI around the stripe would require a large level of processing and so slow the algorithm to an intolerable level. The development of a technique that would allow both edges of the stripe to be defined is the ideal but would result in the process more than doubling in complexity. The unreliability of the tool to identify a stripe edge in raised turbidity seriously handicaps its usefulness for the system. The need to train the tool prior to operation is inefficient and more suited to a more standard environment.

Caliper Tool

The caliper tool offered a more promising operating principle that gave more information that could be utilised and manipulated to allow the system to carry out its task more effectively. The defining an edge pair would at least allow a improved ability to quantity the dimensions of the stripe. As with the Edge tool a level of training was required prior to operation both for the development of a statistical model and for definition of the region of interest.

Identification is by comparison working on the characteristics of contrast, position, polarity and separation. The polarity of an object is the definition of the edge pair, with one edge offering a positive polarity and the other a negative. Position is defined by the measurement of centre point between the two edge pairs and then measuring where this point is positioned within the inspection region. The separation is simply the measure between the edge pairs. These are illustrated in figure 8.11.

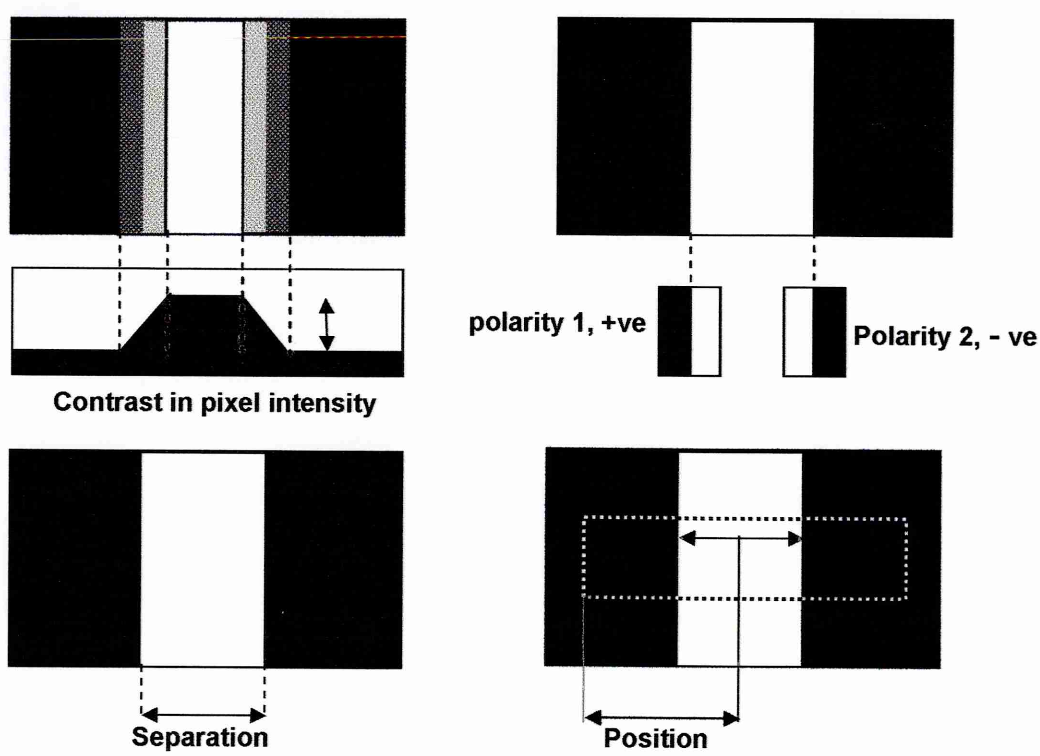


Figure 8.11: Edge pair characteristics

Tests on the technique were applied as before with the centre of the floating region of interest of predefined dimensions positioned in the centre of the edge pairs. Once again the technique performed well in lower turbidity ranges but as expected with a preset size allocated to the region of interest offered a lack of flexibility in close wrapping of the stripe region. A similar technique to that used with the blob tool was applied utilising the known width x of the stripe to set the width of the floating ROI. There is no dimension value offered though for the y axis as the limits of the stripe fall outside of the inspection range meaning the height of the ROI would continue require a predefining. Increasing the inspection area would dramatically slow the processing of each image as was thus not considered as an option. To achieve a closer fit the inclusion of an operator control was made to control this ROI dimension.

In conditions of increased turbidity though, the caliper tool suffered the same difficulties as those experienced by the edge tool. It was noticed that this tool was actually more inclined to lose the stripe than the edge tool, a factor that was probably due to the requirement of two identifiable edges. The advantage of this technique is in the offering of the stripe width, which is measured across the ideal portion of the stripe. This allows certain adjustments to be made, but without correct data for the y axis component, the usefulness of the tool for this application is limited.

8.1.1.5 Discussion

Each of these techniques was applied to the system with varying levels of success, but their application to the task is limited. The requirement of the edge and caliper tools to operate within a reduced inspection region is a notable disadvantage. Much of the stripe falls outside of the inspection region and so data gained from its analysis is lost, restricting the flexibility of any technique that includes their use. Increasing the dimensions of the inspection region sufficiently would only serve to slow the processing of individual images to an unacceptable level.

The effects of increased backscattering noise are to greatly destabilise the processes. Noise blurs the subject of the image making effective stripe definition limited. The edge and caliper tools rely upon the recognition of the stripe edge, but intense backscatter will degrade this edge sufficiently to make its successful identification through these techniques erratic. The tendency of these tools to lose the stripe is further disadvantage as it leads to a crashing of the algorithm.

Of the three the Blob tool was the most successful supplying sufficient data to enable to the floating region of interest to close tightly around the stripe region. The tool is also not limited by the requirement of the inspection range, although it could be applied to improve processing speed. Increased turbidity though once again created the problem of stripe definition. In extreme cases this led to an expanded blob region, far beyond the realms of the stripe, as the Blob tool identifies pixel grouping through connectivity. Therefore any adjacent pixel within the specified intensity range will be included in the isolated region.

This has a follow on effect on the positioning of the ROI as the centre of gravity of the blob is offset from the stripe. The blob tool is generally the more stable of the techniques. As long as two adjacent pixels exist within the threshold range set by the operator, a region of the image will be identified and isolated

8.1.1.6 The extraction process

The process of extraction of the isolated visual information is relatively straight forward. A further inspection image is defined on the operator interface and a blanket value of 255 subtracted. This ensures a totally black image is used as a canvas for the addition adding of the stripe extracts. The floating region of interest is precisely mimicked by another ROI taking the same dimensions and coordinate positions on the addition screen. On completion of the isolation process the selected portion of the image is transferred to the second ROI. Successive isolated regions are then added to the screen as the stripe is scanned across the field of view of the camera, building a cumulative image of the target region.

The process was seen to behave well through the trials and due to the rectangular shape of the extractions a closely knitted image could be achieved. Gaps in the cumulative image will occur though, dependant upon cross field scanning speed and the speed of processing. Across several scans these gaps will be filled but require overlaying the extractions, this resulted in pixel values adding to each other and invariably led to a maximum value of 255 and left white patches in the image. To overcome this unwanted effect a 255 value was subtracted from the area within the region of interest to reblack the region prior to the addition of the visual information.

The use of the rectangular region of interest did however hold disadvantages. The excess information carried through with the stripe still appears on the cumulative image as noise. When these extractions are knitted together the effect is a row of stripes with backscattering effects still present. This is shown in figure 8.12.

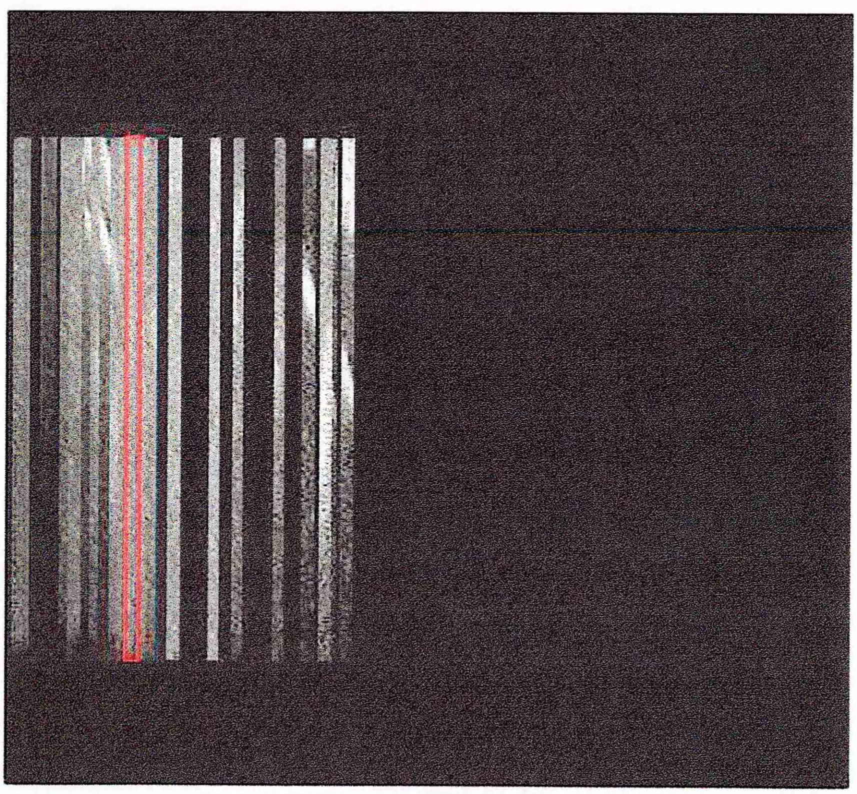


Figure 8.12: Example of the addition of extracted stripes in the cumulative image

This also results in any geometrical target information held within the stripe being less defined, providing a two dimensional image to the operator. To gain a three dimensional view of a target object, the aspect of the stripe must be more defined, however this is not achievable through this system.

A final but very important consideration to be made at this stage is the stripe geometry. As discussed in the previous chapter, when a target object is imaged the geometry of the stripe will alter across the target. Vision Blox does not have an ability to set a non uniform freehand region of interest. A limited range of standard geometric shapes are the only options available and extractions can only be made within the boundaries of these shapes. The difficulties that this creates are illustrated in figure 8.13.

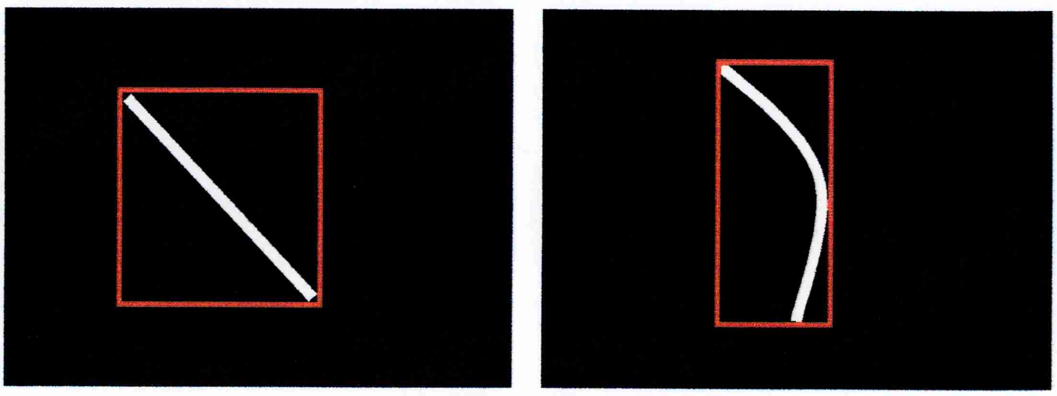


Figure 8.13: Examples of the effect of altering stripe geometry on a rectangular region of interest.

Two stripes that are geometrically altered by their projection onto target object can not be efficiently isolated by a region of interest of standard geometric shape. If we consider that the black visual information held within the ROI is excess it is clear that this feature holds considerable consequences for the compilation of the final image. A possible solution to the problem is a series of small ROI's each configured on their unique plane, which would isolate small regions of the stripe individually. This proposal is illustrated in figure 8.14.

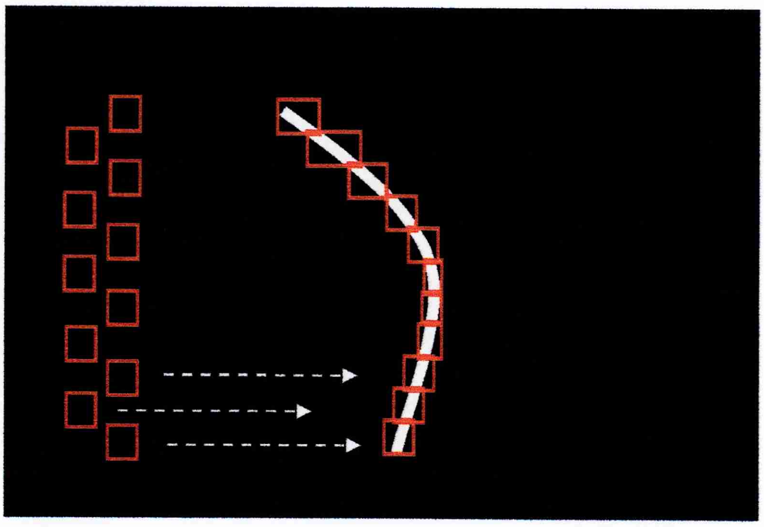


Figure 8.14: Proposed solution to the limited region of interests available within Vision Blox

This technique would require a lot of processing as each segment of the stripe would have to be assessed individually to obtain the coordinates and dimensions needed to position an ROI around it. With the importance placed on processing time this was not considered as a viable option.

At this stage in the research project it was decided to assess a new image processing tool for suitability to the system. The sponsors (DERA) requested that the programmes be compiled in LabVIEW 5.1; this was suggested to conform with the development tools used at Bincleaves.

8.1.2 ALGORITHM DEVELOPMENT IN LABVIEW

LabVIEW is a graphical development system specifically designed for measurement and automation applications. It offers data acquisition, instrument control, measurement analysis, and data presentation to the developer within a highly flexible system. Predefined 'IMAQ' tools are available to the developer that require no actual programming and which offer a range of criteria that can be altered to suit their operating needs. Initial programming of the algorithms was performed within LabVIEW 5.1 which was updated further on in the project to LabVIEW 6i.

As with Vision Blox, live images are fed into the system and progressive image grabs can be obtained and manipulated, to achieve the final result. The Labview system though is intrinsically very different from that of Vision Blox and required a certain amount of time to explore the system and become accustomed to its method. Development began with attempts to reproduce the processing techniques built within Vision Blox. Algorithms built within LabVIEW are described as virtual instruments or vi's and on inspection appear very different from standard programming languages. Full scripts for the LabVIEW vis' mentioned are shown in Appendix **B.**Operator interfaces are provided with a range of functional tools for analysis and manipulation, and linked to the vi itself.

It was discussed in the previous chapter the processing of a series of stripe grabs can be considered in three stages, Stripe identification and isolation, stripe extraction and cumulative image compilation. Vision Blox algorithms were based upon the use of various identification tools, inherent to the system. The limitations of these tools were primarily in definition of the stripe region in raised turbidity.

8.1.2.1 Temporal Differencing

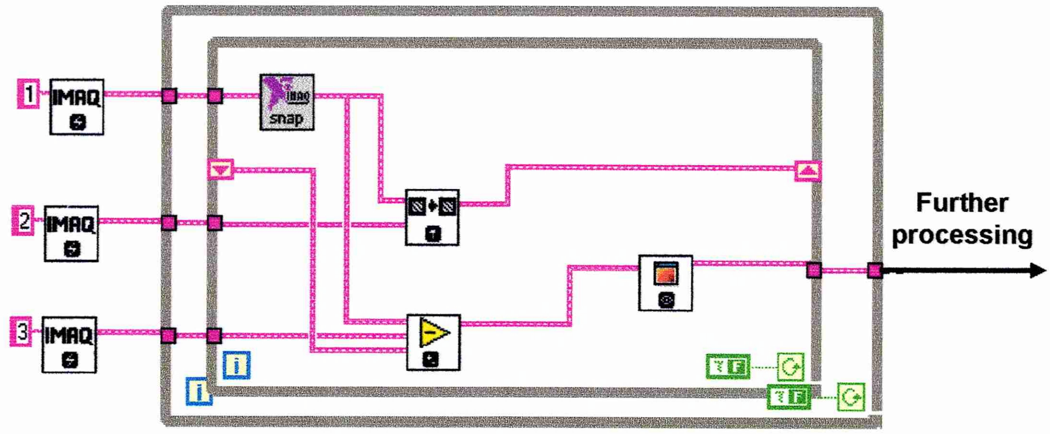
With the inclusion of the Temporal differencing technique, a level of backscatter can be removed from the image particularly from the scanning beam region, improving the definition of the stripe. Transferring this process to a vi, presented itself as an appropriate starting place.

In theory this process is a relatively simple one requiring a looping of a grab, transfer, grab, subtract process but difficulties were being faced with the loss of the second grab after the subtraction of the two images took place. This second grab image was required to replace the first grab once the subtraction process was carried out.

Various techniques were applied but did not carry through the operation successfully, whilst this problem was considered further a slow stand in technique was applied to allow further processing development to continue. The description of this stand in technique in detail is unnecessary but a brief outline can be given by;

Two initial grabs are taken at identical moments in the scanning process. The first is then taken directly to the subtraction tool. The second is then transferred and held within a local sequence whilst a second grab is obtained. The held image is then taken to the subtraction tool and subtracted from the second grab. Then correct sequence is controlled through a true/false case structure to ensure the correct image is used throughout the process.

As mentioned this technique slowed the running of the algorithm significantly as it required a large level of processing, but the problem of holding the image after subtraction was eventually solved with the addition of an image copy and hold function. A delay in development caused primarily by unfamiliarity with the system options. The correct process that was eventually devised can be seen in figure 8.15.



Key:

- IMAQ create: creates a live image
- IMAQ snap: acquires a single image
- IMAQ copy: copies the specifications and pixels of one image
- IMAQ subtract: subtracts one image from another
- IMAQ WindDraw: displays an image in an image window

Figure 8.15: Temporal differencing through LabVIEW

Imaq create initiates the live image that is passed through the grab module to create the first grab image. From here the image is copied and stored. The next image is then grabbed, copied and stored then transferred to the first subtraction function where the initial image has been looped around and brought to the second function of subtraction. The subtraction of the first image from the second is then carried out and a resultant image is achieved and passed on for further processing. Meanwhile as another grab is taken, copied, stored and passed to the first function of subtraction the copy of the second grab is looped and sent to the first function of subtraction. Examples of the process when applied to a stripe imaging the barrel target are shown in figure 8.16.

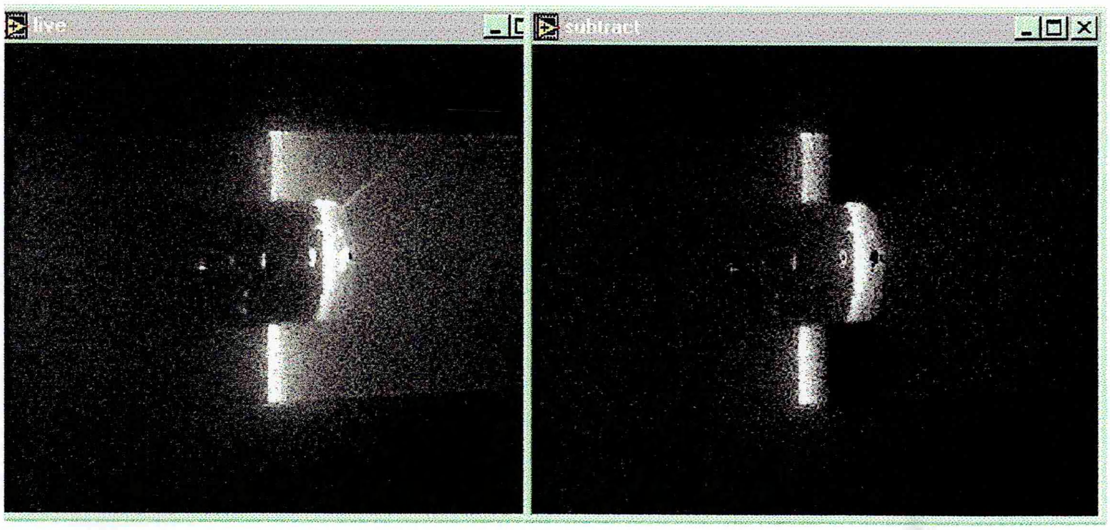


Figure 8.16: Live scanning stripe in turbid medium before and after the application of temporal differencing

The beam path of the laser clearly visible in the live image on the left is effectively removed by the temporal differencing shown on the right. This technique was processing intensive and whilst resulting in reduced backscatter intensity, there was room for improvement. To enable the more efficient definition of the stripe, a process was required that was not only quicker through processing, but also removed greater levels of backscattering noise from the image.

8.1.2.2 Stripe Isolation

For the development of the stripe isolation portion of the algorithm, LabVIEW offered two particular options that could perform the basis of the any technique. Edge detection could be used as in the techniques developed through Vision Blox but with a further ability to contour the entire edge of the stripe. This essentially combines the properties of the edge and caliper tools used through Vision Blox, whilst further applying the detection of all edges to the isolated region. The inclusion of this technique was tested on the tracking of the laser stripe as its was projected onto the target barrel. An image capture of this technique in action is shown in figure 8.17, with the addition of white writing applied the barrel surface.

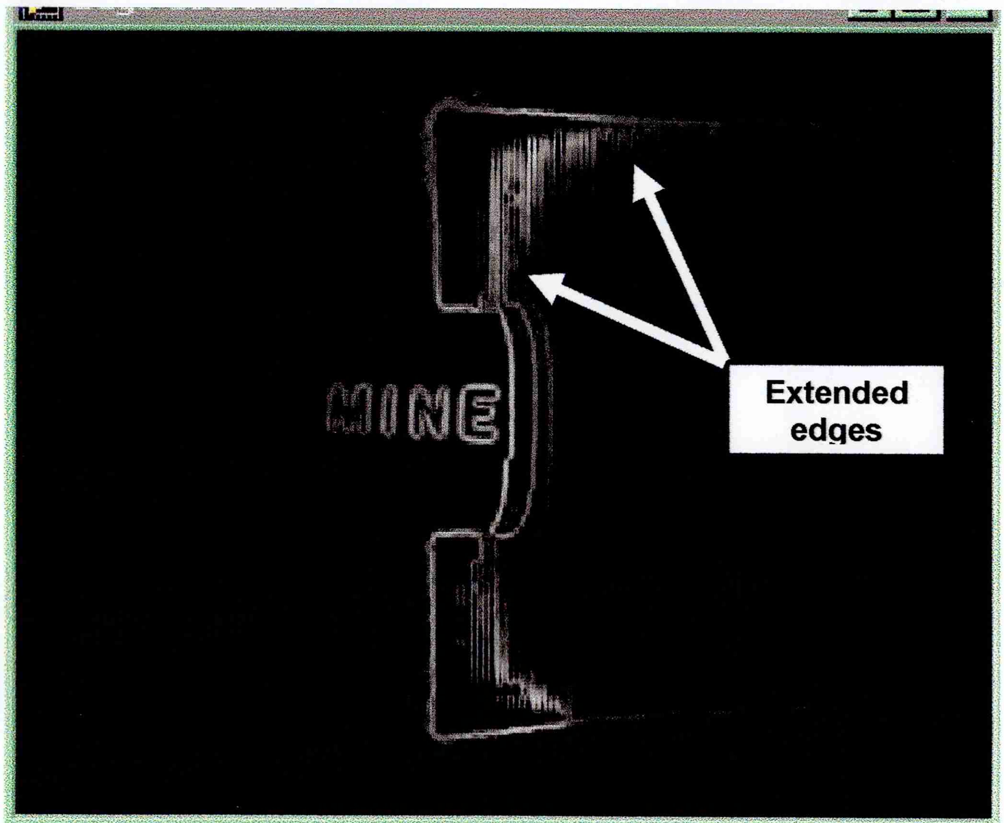


Figure 8.17: Edge detection process through LabVIEW, Scanning of barrel target at 3m (40g bentonite).

The Edge technique effectively mapped the edges of the projected stripe in clear water conditions, but experienced problems as turbidity was introduced into the tank. This was not only due to the reduced ability of the tool to define the edges of the stripe but also in the way in which the isolation of the region is carried out. The image above shows that the isolated region is extended towards the end of the stripe and on the trailing edge of the scan, this occurs as the edge function looks to encompass the desired range within a larger body. In doing so it is also including undesirable visual information, in particular from more intense backscatter regions such as those experienced around the ends of the stripe and the trailing edge. The process can be adjusted to allow the smaller features that fall within the required range to be isolated independently, but requires a default pixel width to allow the setting of an edge within the image. Thus to use this process to set a region to be extracted would result in the inclusion of excess information by default. The main problem with the edge tool is that its primary function is not to isolate a region, but to draw an edge on the image around it. Further processing could be applied to define the internal properties of the edge to set the limits of the required region. This though would result in the necessity to include a further image window in which the edge can be drawn without affecting the original image. More processing included in the algorithm and the more image information held within the algorithm will result in slower overall processing time across the algorithm.

The second option was that of a thresholding filter that allowed a freehand region of interest to be drawn around the selected area. Thresholding works very much on the same principle as the edge tool, but does not look to group into isolated pixel regions, although this is an option, nor does it actually add information to the image to define its parameters. The region of interest could then contour the threshold boundary and was not restricted by geometry in the case of Vision Blox. ROI's can be restricted to standard geometric shapes as in Vision Blox but with the further inclusion of a freehand option which is used in this case. Figure 8.18 shows the efficient isolation of the stripe region achievable. Threshold range could be preset within the tool or placed as a control on the operator interface.

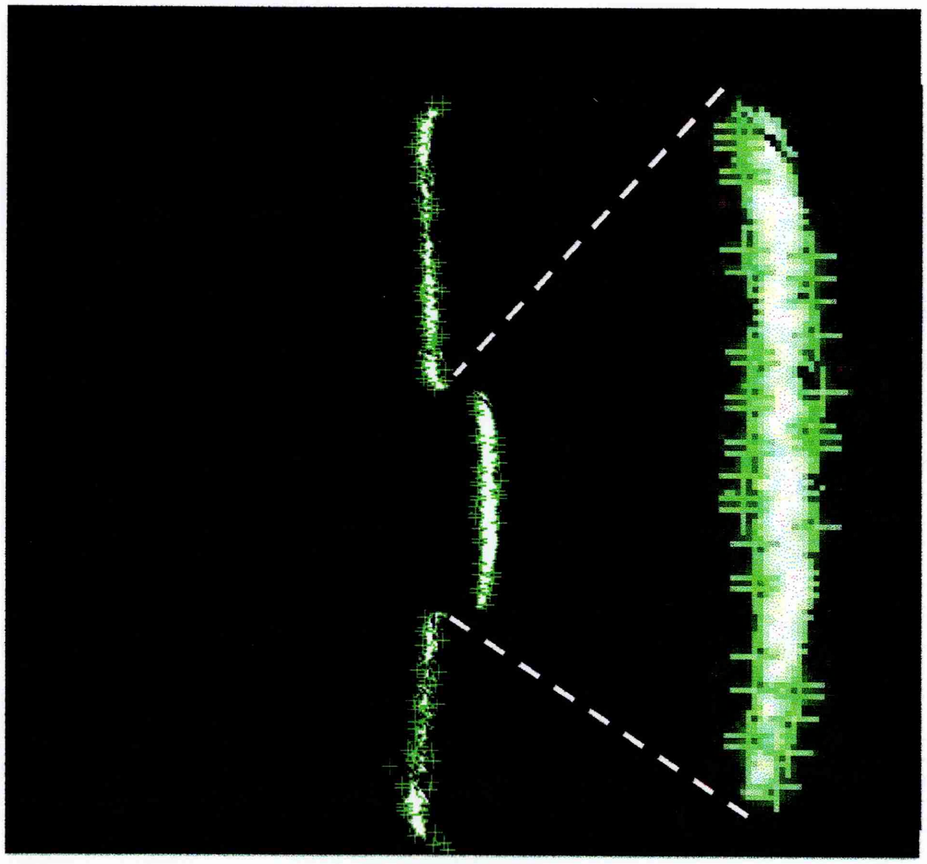


Figure 8.18: The setting of an irregular region of interest (ROI) contouring a stripe

The creation of the region of interest around a stripe image involved the use of several functions inherent to the LabVIEW system, combined in a novel way that not produced the region of interest but allowed the system to extract only the visual information held within its boundaries.

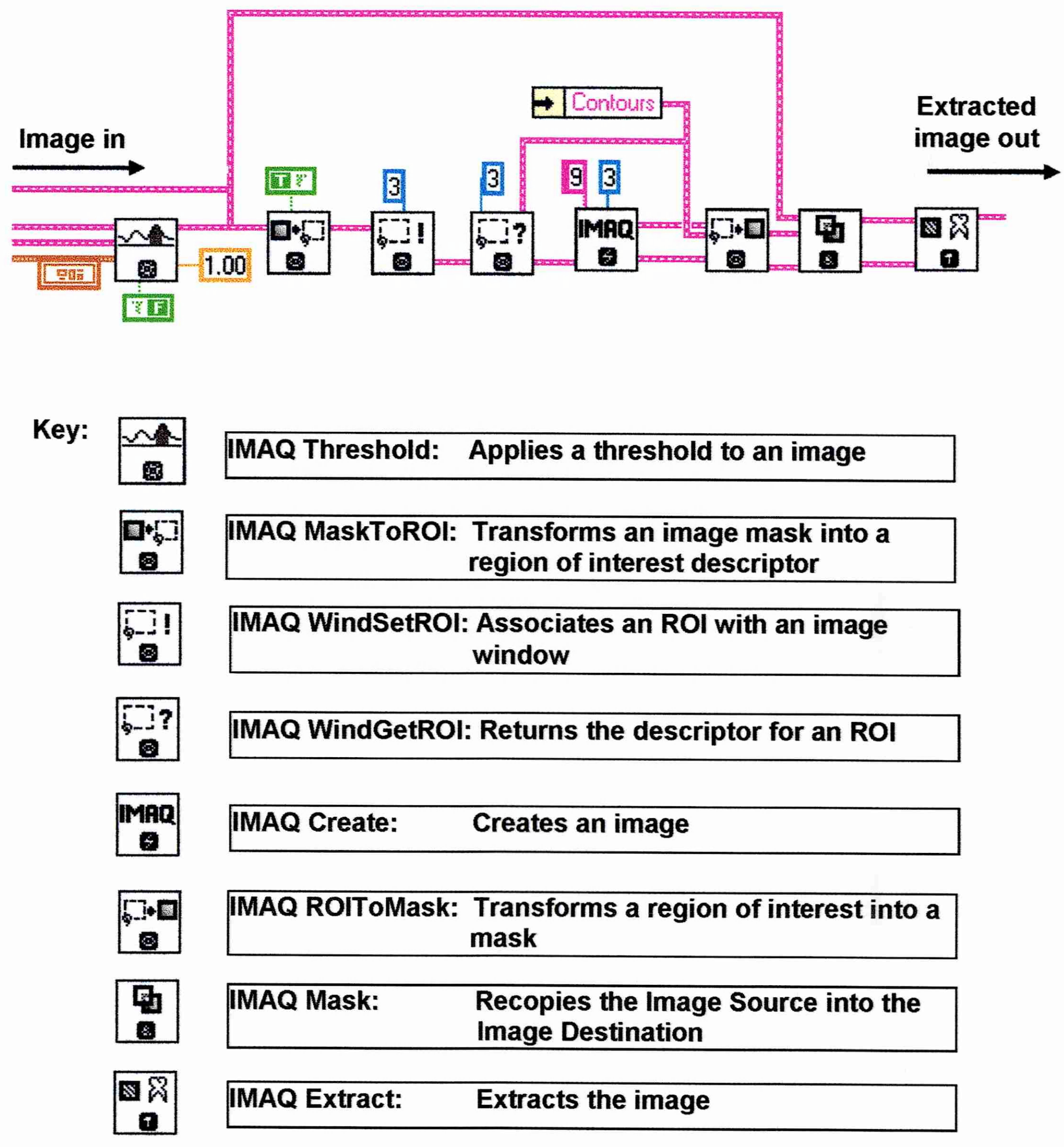


Figure 8.19: LabVIEW stripe isolation process with ROI

Referring to figure 8.19, the process can be tracked by the following:

- Threshold range is set by the operator and the task performed creating a mask over the selected regions.
- The process then operates around IMAQ Create which introduces an image base.
- The information from this threshold limit is then transferred to IMAQ MasktoROI which creates the dimensions of the freehand ROI around the limits of the required region.
- IMAQ WindSetROI associates the ROI to the window in which it should be displayed.
- IMAQ WindGetROI describes the ROI within the window.
- At this point the mask and ROI region is defined within the window allowing IMAQ Mask to transfer only the information held within the mask and bounded by the ROI. The ROI and the image that it contours are now intrinsically bound together,

The extraction of visual information from within an irregular region of interest is an option that is not described within LabVIEW user manuals, allowing only extractions to be carried out within preset shapes as with Vision Blox. This was confirmed by consultations with LabVIEW development staff. But exploration of the properties of the above tools allowed a manipulation of their properties to develop a process that was new even to LabVIEW development staff.

Referring now to the illustration shown in figure 8.20; if we can imagine that an image of a stripe is defined by a threshold level around which a masking occurs with a rectangular shape and a freehand ROI is drawn to define the stripes exact dimensions **A)**. A new operating window is then defined in **B)** with no visual information held on it. The ROI dimensions can then be taken, on their own and placed in the new operating window leaving only the ROI in this window and carrying no visual information. This region of interest is then redefined to the original image which is instructed to place the mask **C)** within the new operating window. Consider the question: How do you make a square peg fit into a round hole? The answer is to force the peg into the hole, resulting in the excess being cut off. In the case of he stripe the predefining of the region of interest in the new operating window means no alterations can be made to the pixel values outside of the ROI, so the mask does not consider areas outside of the ROI to be an operating region therefore can only transfer information that corresponds to coordinates that fall within the ROI. This leaves only stripe information extracted **D)**.

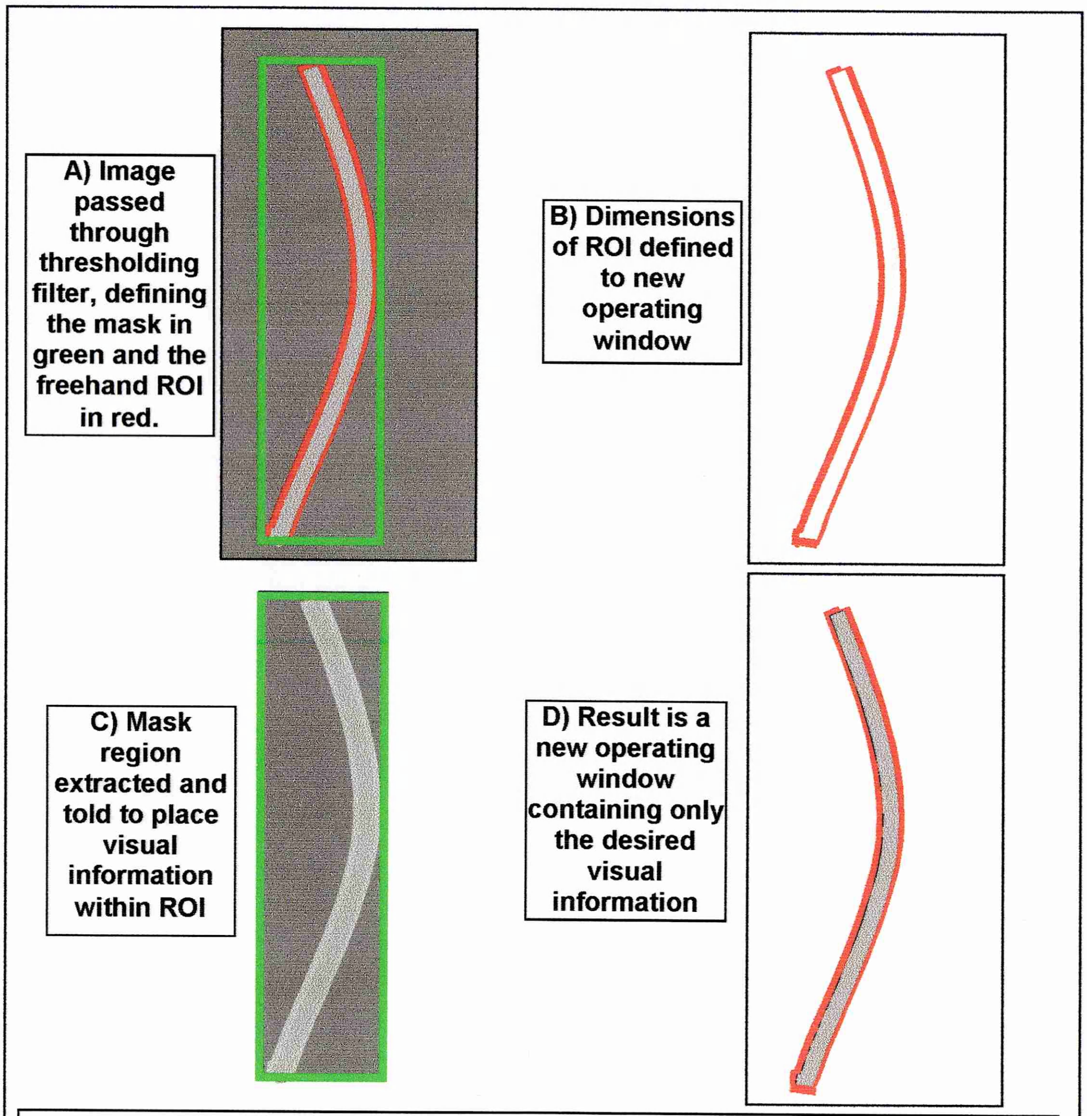


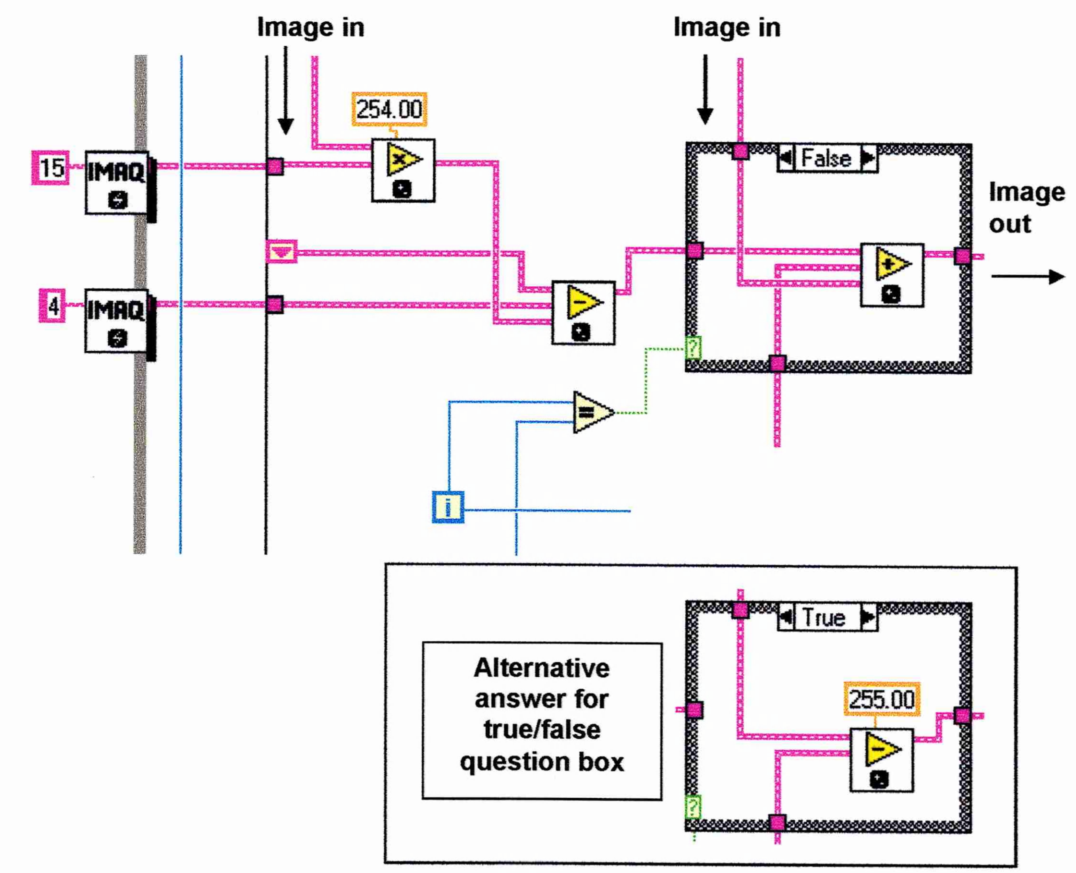
Figure 8.20: Novel technique for isolation and extraction of the stripe

Whilst the technique seems laden with processing the performance time can be weighed against its success. It was the only truly efficient ROI based isolation process that can be applied to a stripe that experiences constantly changing geometry. The Technique now effectively combined two segments of the entire process, with isolation and extraction now included in one effective technique.

8.1.2.3 Image compilation

With the development of an effective extraction technique the final consideration was to produce a technique of image addition on a cumulative window. Stripe extraction was now in the form of visual information of irregular shape thus giving the operator more depth in the image through an improved view of the aspect of the stripe. The addition of several stripes could now be constructed in a clearer way. Figure 8.21 shows the construction of the process within the vi.

As with the technique used in Vision Blox, to prevent pixel values adding together as the stripes overlap, the precise region that the extract will be added to, must first be blacked out. To obtain this region, two images must first be created by the extraction process, one image to act as the template whilst the other provides the visual information. The template is first passed through a multiplication constant of 254, thus ensuring that all pixel intensities hold a value of at least 254. The reason for this is that the values of this image will be subtracted from the cumulative image prior to the stripe region being added and ensures that the area in which the stripe information is added, results in near zero pixel values. Ideally this should be a value of 255 to entirely blacken the region but the Region of interest in this form is now bound to the image of the stripe and not a predefined geometric shape. Total removal of the image would result in a loss of integrity of the ROI. As it stands the image is 99.6% depleted. Note: there is no visual information held outside



Key:

- **IMAQ Multiply:** Multiplies two images or an image and a constant
- **IMAQ Subtract:** Subtracts one image from another or a constant from an image
- **IMAQ Add:** Adds two images or an image and a constant
- **IMAQ Equal:** Returns TRUE if x is equal to y. Otherwise, this function returns FALSE. This function accepts complex numbers

Figure 8.21: Addition of images to the cumulation image

Figure 8.21 displays the portion of the algorithm dealing with this technique. The inclusion of the question box is purely to allow the operator to reset the cumulative image. The IMAQ equals function can be made to respond either to a reset option on the operator interface or a set number of stripe grabs passing through the algorithm. When the reset is instigated or the number of grabs reached the equals function operating the 'True' window. The true window will immediately subtract 255 from the cumulative image thus returning all pixel values to zero, then return again to the false window.

The vi. was tested in a high level of turbidity to assess the ability of the algorithm to isolate a stripe region. 100g of bentonite was added to the tank water equating to an average NTU reading of 0.667. The effect of this level of turbidity is that no scanning beam is visible on the back wall of the tank at 4m. Figure 8.22 shows the addition of successive grabs to the cumulative image under testing. The threshold range is 228 to 255. The full vi algorithm for this process named 'Laser stripe 1a.vi' is displayed in appendix **B**.

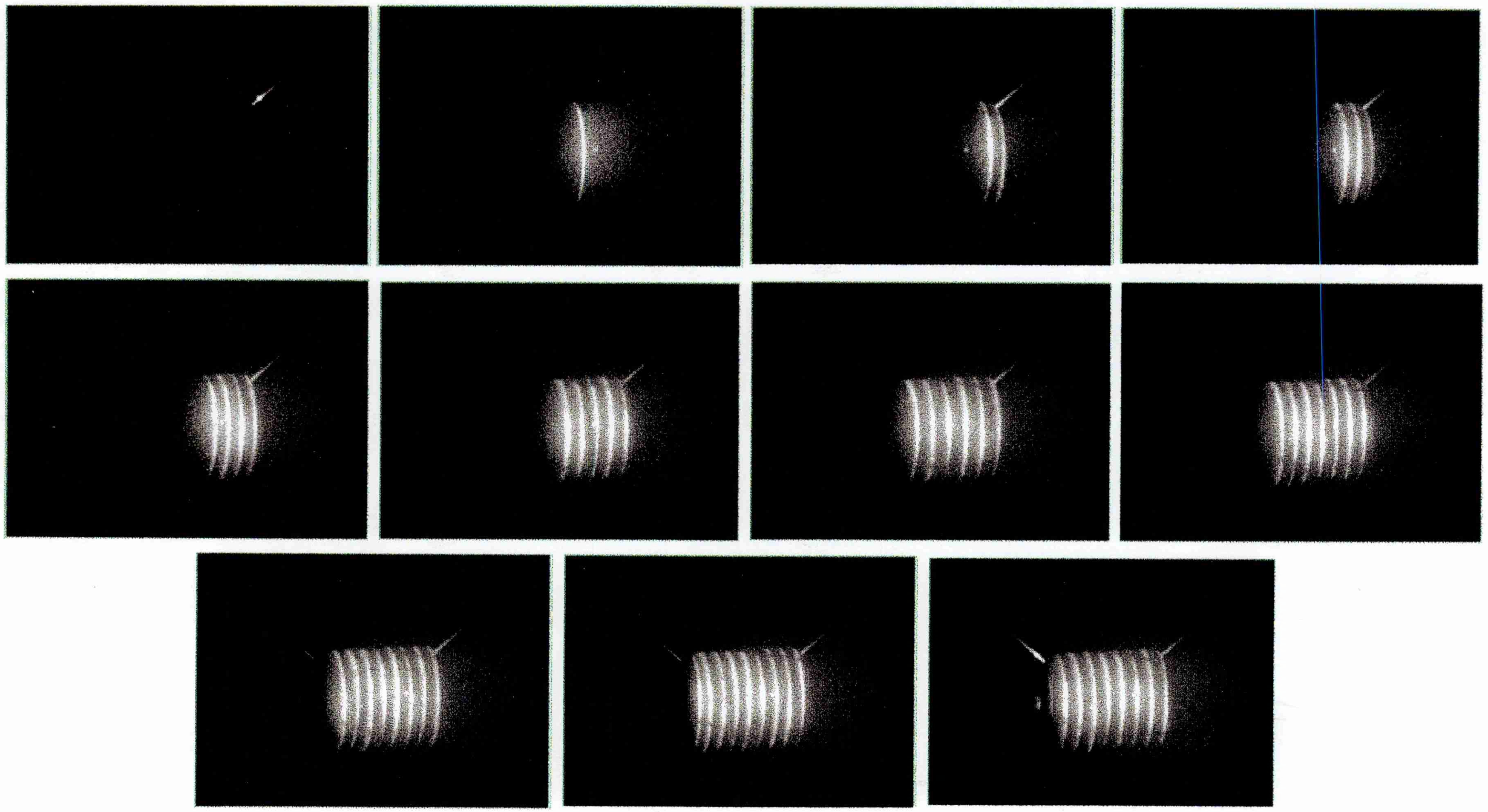


Figure 8.22: 'Laser stripe 1a.vi' performing addition process in the cumulative window. The barrel target is at a range of 2.5m with the addition of 100g of bentonite (average NTU reading = 0.667)

If a comparison is made between these results achieved through the algorithm and an unprocessed or raw stripe captured under the same conditions we can see the effectiveness of the processing. Figure 8.23 compares a raw stripe against a processed stripe in the same position on the barrel. No lamp image was possible in this level of turbidity

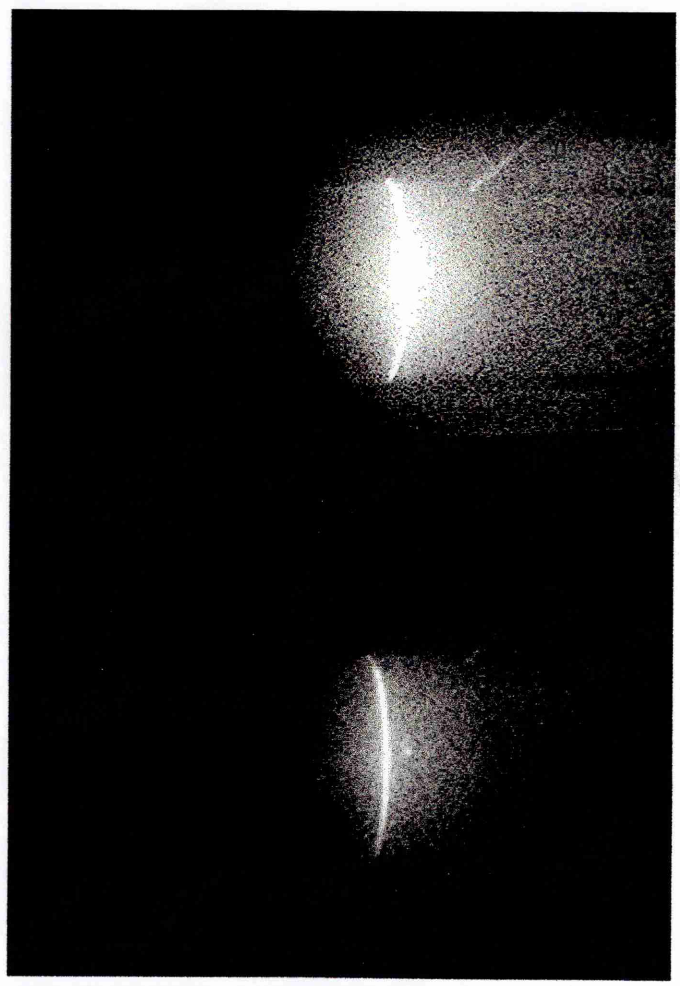


Figure 8.23: Unprocessed stripe compared to stripe processed through 'Laser Stripe 1a.vi'.

8.1.2.4 Discussion

The temporal differencing technique worked correctly but affiliate/alternative techniques would have to be explored. The images shown in figure 8.23 still show a level of scattering noise entering the final image. This will have a cumulative effect on the construction of an image of the target. The backscatter occurring in the beam scanning path has been almost completely eradicated from the final image leaving the dense, high intensity scattering that occurs around the immediate stripe region. Much of this could be further removed by a tighter threshold range being set. The stripe itself is significantly better defined, and the curved surface that the stripe in projected upon denotes the geometry of the target object at that point. Further examination of the stripe shows a narrowing towards the ends of the stripes and a lessoning in intensity, thus further defining the shape of the target object.

The application of the mask and region of interest extraction process was controllable by a threshold level, which can be set by the operator during runtime. The technique proved to be a lot easier to control than the edge, line and blob tools based processes constructed within Vision Blox. The control was subtle and could allow a definition between the projected stripe and a high level of backscatter which caused many of the stability problems experienced in the tools used in "Vision Blox". The process no longer required a complicated ROI positioning technique and so did not lead to algorithm failure, if a region of the image was not found that could be isolated, the system would just ignore that particular image and continue smoothly.

There were problems to be addressed within this process though! Small levels of backscatter were not being removed in the differencing and extraction processes, particularly around the stripe region and the path of the laser beam. This was due to the reliance of the system on the success of the threshold level. Despite the greater discrimination of pixel values that the system allowed, a certain level of backscatter will still fall within the threshold range. The mask/ROI isolation and extraction technique was not able to discriminate the required region from those areas and will transfer all the pixels falling within the intensity range.

With regard to overall processing time, individual grabs could be achieved every 0.5 of a second. This was closely comparable to times achieved the Vision Blox processes. This was though a first draft for the processing of the images through LabVIEW

In particular the success of the thresholding function to combine aspects of the isolation process with the extraction of the isolated stripe region, directed the search towards functions that could effectively replace the need to pass images through the temporal differencing technique. LabVIEW functions clearly show a high level of flexibility and stability whilst still offering the developer the ability to define limiting criteria within a wide range of options.

With the success of the thresholding process, possible replacement of the processing intensive temporal differencing technique would have to be explored. The highest concentration of backscatter occurs in or around the stripe region and whilst the temporal differencing process did reduce the intensity of this characteristic a more simplistic process could perform the same task.

8.1.2.5 An Assessment of the temporal differencing technique

Temporal differencing essentially allows common features of the back scatter to be rejected. As the stripe in scanned the primary common feature is that of the laser scanning beam which emerges in the image in the form of a sheet spreading out towards the target. Figure 8.24 displays this in a three dimensional form. Particularly in high turbidity the density of backscatter experienced within this region can be considerable but the greater density of the backscatter that occurs the more effective the temporal differencing technique is. Individual scattering events are chaotic and so only an overall pattern can be predicted; in a less turbid medium therefore the likelihood of scattering events occurring in two successive scans in the same position on the image is small. The technique is highly effective though in the removal of the extremes of the scanning beam as these are the regions where the intensity of the backscatter is greatest as the scan slows.

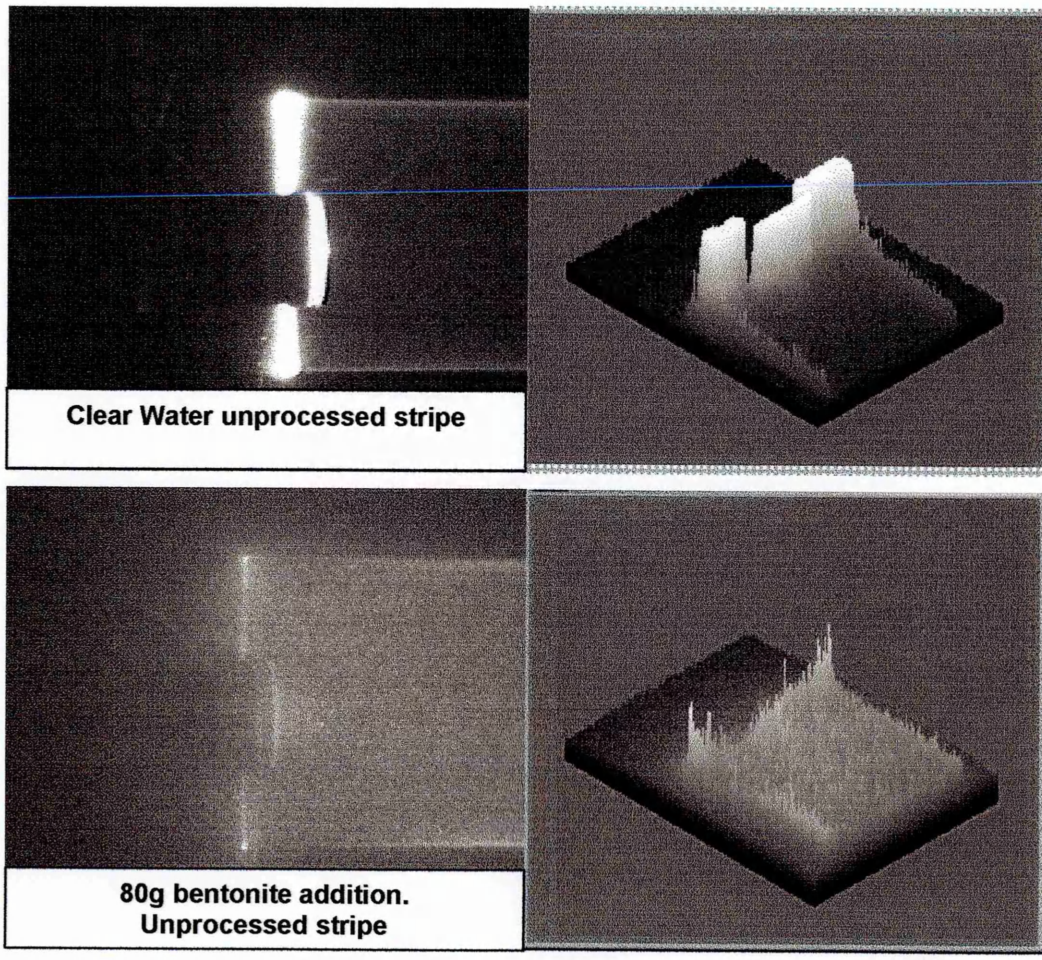


Figure 8.24: 3D interpretation of unprocessed stripe grabs: Predominance of backscatter occurs in the scanning beam path

Where the temporal differencing does come into its own though is in the rejection of 'bright spots' that can occur within the range of the scanning beam. The technique can effectively differentiate between the imaging of still features and a moving feature. If we consider that the aim is to image not the target but the stripe as it falls upon the target then the advantages of this technique become clearer. The stripe in successive grabs will have moved across the range of the scan. In the near-field though, the range of the scan is considerably smaller. In this region even a relatively small object can occupy a sizable proportion of the beam scan resulting in a high level of light reflecting off its surface, causing a 'bright spot'. The movement of the scanning stripe in the near field will be less pronounced allowing temporal differencing to discard these 'bright spots'

There are disadvantages though with temporal differencing. As the technique eliminates unwanted regions in the near field it also restricts short range imaging of target objects. To increase stripe grab separation in the near field the horizontal scanning speed must be raised. This is not enormously disabling for the system when used as an inspection tool, as the speed can be altered by the operator or automatically through knowledge of the range. It can restrict the ability of the system to operate as a general underwater viewing tool though. As Increased cross field scanning speed raises the ability of the system to visualise objects over shorter ranges it will in-turn decrease the possibility of identifying objects over greater ranges.

The key disadvantage however of the temporal differencing technique is the processing of the image. The holding and movement of an image through an algorithm requires a large level of data transfer and storage, as the system identifies the image in terms of a large matrix of pixel intensities. In LabVIEW the technique requires the images to pass through several functions to achieve a limited result. Each function must collect, process, reform and send the visual information held within each image. To heighten this problem, in the case of the temporal differencing there are always two images being held within the algorithm simultaneously.

8.1.2.6 Further development

For the optimisation of the algorithm processing speed, it would be preferable to replace temporal differencing with a technique that required the processing of only one image at a time, whilst passing the image through a minimum number of functions. Due to the properties of the images obtained through the laser stripe system, the search for this technique was primarily aimed within functions designed particularly at the processing of grey-scale images.

The installation of the upgraded versions of LabVIEW and IMAQ offered new functions that could supply possible replacement processes. These were explored and assessed before assembly into the algorithm.

IMAQ BCGLookup, applies gamma correction to an image. Gamma transformations operate by separating image information, expanding high greyscale value whilst decreasing low greyscale values. The result is an increase in contrast over brighter regions. Thus it was felt that this property could be of great value to the stripe isolation process. Correction is performed by computing and applying a look-up table. These corrections control changes made to the transfer function represented by the look-up table.

The following figure (8.25) is taken from the IMAQ concepts manual [8.2] and helps to explain the use of these lookup tables in the process. The horizontal axis represents the intensity value in the input image, whilst the vertical axis represents the intensity values in the output image. Each input intensity value is plotted and its intersection with the particular lookup curve denotes its value in the output image. The value of γ is denoted by the gamma coefficient set by the operator on the interface shown in figure 8.26, and ranges from 1 to 10.

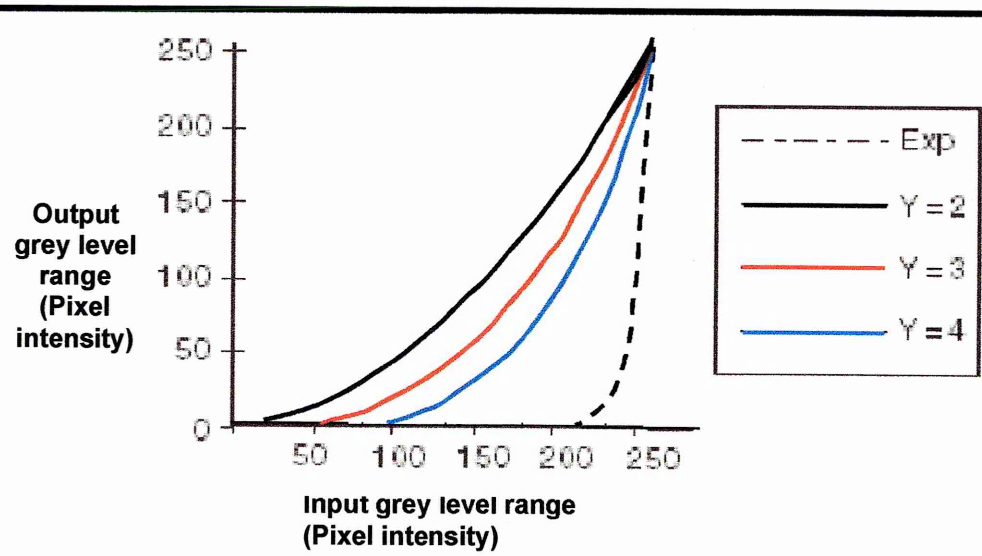


Figure 8.25: The operation of lookup tables by the gamma correction function (IMAQ concepts manuals)

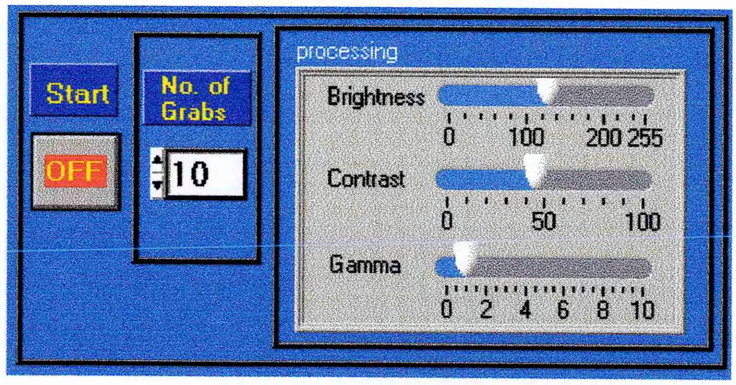


Figure 8.26: IMAQ BCG Lookup operator interface

The higher the gamma coefficient set the greater the intensity correction. Look up table (LUT) transformations include brightness and contrast settings and can be used to highlight image details in areas that contain important information. This is done at the expense of regions that do not contain visual information considered to be of any importance. These functions operate by converting input greyscale values into output greyscale values within the definition of limits set by the operator. With respect to the continued processing of the image within the system, their ability to not only filter but perform image alterations through the filtering process would allow further functions to operate more efficiently within their own remits.

The affect of including this function within the algorithm would be to increase the contrast available between the bright regions of the image (the stripe) and the lower intensity regions such as backscatter noise. The Gamma coefficient can then be adjusted by the operator to react to altering conditions. This would result though in the level of visual stripe information being adjusted or lost. As turbidity increases however the level of visual information available from the stripe is reduced. With temporal differencing applied in turbid conditions the expansion of the scattering region will result in scattering intensity values being subtracted from regions within the immediate area of the stripe. Thus variations in pixel intensity values obtained within the stripe that could be assessed by the operator as useful visual information may in fact be a 'red herring'. A vi was constructed with the temporal differencing technique replaced by the IMAQ BCG Lookup function, and named 'gammaprocessing full run.vi' The algorithm was further trimmed to assess the ability of the function to remove from the image all but the required region, thus leaving a pixel value of 0 across all areas of the image, outside of the processed stripe This vi was entitled 'minimal gamma 1.vi' and both these vi's are shown in Appendix B.

The second option offered by LabVIEW was that of a greyscale morphology function. This can be used to alter the shape of regions by expanding or diminishing dark or bright areas at the expense of the others. They are generally used to smooth gradually varying patterns or increase contrast in boundary areas. There are several options which can be selected to perform particular transformations to an image. These are;

- **Erosion;** That reduces the intensity if pixels that are surrounded by neighbouring pixels of a lower intensity.
- **Dilation**; which increases the brightness of pixels surrounded by neighbouring pixels of a higher intensity.
- **Opening**; this removes bright pixels that are isolated by regions of low intensity pixels and smoothes boundaries.
- **Proper-opening**; which also removes bright pixels that are isolated in dark regions but smoothes the contours of particle regions
- **Closing**; which removes dark pixels that are surrounded by regions of high intensity pixels and also smoothes boundaries..
- **Proper-closing**; which also removes dark pixels that are surrounded by regions of light pixels but also smoothes boundaries
- **Auto-median**; which generates simpler particles with fewer details.

Examination of these functions can immediately allow an isolation of possible useful operations. The erosion and dilation functions reduce or increase the intensity of pixels in relation to the intensity of the pixels surrounding them. The removal of isolated scattering events would initially appear lend itself ideally to the erosion process. The density of backscattering events that occur in a highly turbid medium however, would limit the effect of the function as their isolation is not clearly defined. The process would also erode the edges of the stripe region a position that is desirable as high turbidity can narrow the stripe region significantly on its own. Further reductions may limit an already limited situation. Dilation would result in an increase in intensity of isolated pixels which is the opposite of the required affect. Therefore both of these functions could be dismissed.

Opening and closing functions act more aggressively by removing the isolated pixels but the arguments used against erosion and dilation apply here as well. The smoothing of boundaries and contours could help in the definition of the stripe but will increase or decrease the characteristics of the stripe region.

Finally the auto-median function alters the image as a sub-function of the proper-opening and proper-closing of the original image. Therefore with the rejection of those processes then this too must be rejected.

Although the functions of IMAQ Greyscale Morphology were rejected an algorithm was written with the inclusion of the proper-opening function set in series with the gamma correction technique in an attempt to demonstrate its effect. This function was selected as it included the basic technique of the erosion and opening functions, and should show the affects of the removal or reduction of isolated pixels that are surrounded by low intensity regions. This vi is shown in Appendix B and named 'minimal gamma 1 with popen filter.vi'.

9 ALGORITHM TESTING

Using the barrel target as a standard, each of the LabVIEW algorithms described were assessed under increasingly turbid conditions created by the supplement of bentonite to the tank. Bentonite was added in increments of 20g, ranging from clear water to 80g. In terms of turbidity this equates to an average reading of 0.103 to 0.579 NTUs. A range of 3.5m was selected; however some results were obtained from other ranges to enhance the analysis.

The inclusion of a level of operator control to each of the algorithms signified that tests should be conducted across the control ranges to asses their affect. The control method alters across the different techniques so are directly incomparable, but images that are considered 'best results' can be generally compared. These can be further compared to arc lamp images under the same conditions.

Still images were gathered for individual processed stripes and full scans of the barrel target. These were stored in the form of 24bit bitmaps in a standard size of 630 x 460 pixels. An analysis programme was written to aid in the direct analysis of each image.

9.1 ANALYSIS ALGORITHM

The evaluation of an inspection and recognition tool as discussed earlier is a subjective topic. The ability to recognise an object is dependent upon the experience and knowledge of those who are attempting to recognise the object. As a consequence, evaluation of the full system is best carried out by visual comparisons. To enable a term of visual improvement to gained in any form, a breakdown of the aims of the processing must be carried out.

The development of these processing techniques, were aimed primarily at the removal of noise from backscattering light diminishing the definition of the imaging stripe edges, as this is basis of the all techniques that follow Therefore the success of the algorithms can be assessed in part by the isolation of the stripe region through the processing method used. This is best shown through analysis of processed stripes and the presence of independent pixel intensities out-with the immediate area of the strip region.

An analysis algorithm was therefore developed based on integral LabVIEW tools, which enabled several properties of the processed stripe image to be evaluated. Named 'intensity, measure and histogram.vi' the vi. was able to call up a captured image and assess the following:

- Number of pixels held within the image: All analysed images were stored as 24bit bitmaps measuring 630 x 460 pixels, thus a standard pixel count should be obtained of 289800. This value was included for both the ensuring of the standard size of the image and to allow percentage calculations to be carried out by the algorithm with respect to the frequency pixel properties across the entire image.

- Number of pixels in intensity range: A graph is drawn of the number of pixels across an entire image holding a particular pixel value against pixel values between 0 and 255. In an unprocessed stripe the pattern of the graph should follow a wide range between these values a perfected processed stripe should show a narrow range across the graph within the boundaries of the isolation process. Due to the large numbers being dealt with when analysing pixels across an image, effective scale of the graph can be very large indeed, therefore the data is presented on logarithmic scale. To enable precise pixel counts for an intensity value, this value can be added and a pixel count given.

- Percentage of area a pixel intensity value can be entered into the algorithm and a percentage of the entire image held by pixels of that value can be given.

- A three dimensional interpretation of pixel values across the entire image produced

- Mean value an average pixel intensity value across the image can be given

- Minimum and maximum values across the image are given

- Finally the algorithm gives an option to define these properties within a particular region or across a freehand drawn line by the operator. This data is presented in the same way as the data for the entire image.

The operator interface for this algorithm is shown in figure 9.1 during analysis of the target barrel illuminated by the arc lamp in clear water at 3.5m. The algorithm was also written in a live feed format to allow analysis of live images. The advantage of this being, that prior to utilising any processing algorithm the nature of the images can be assessed, aiding the operator in the selection of the optimum isolation properties. The full algorithms for both 'Intensity measure and histogram.vi' and 'Intensity measure and histogram live.vi' are shown in Appendix C.

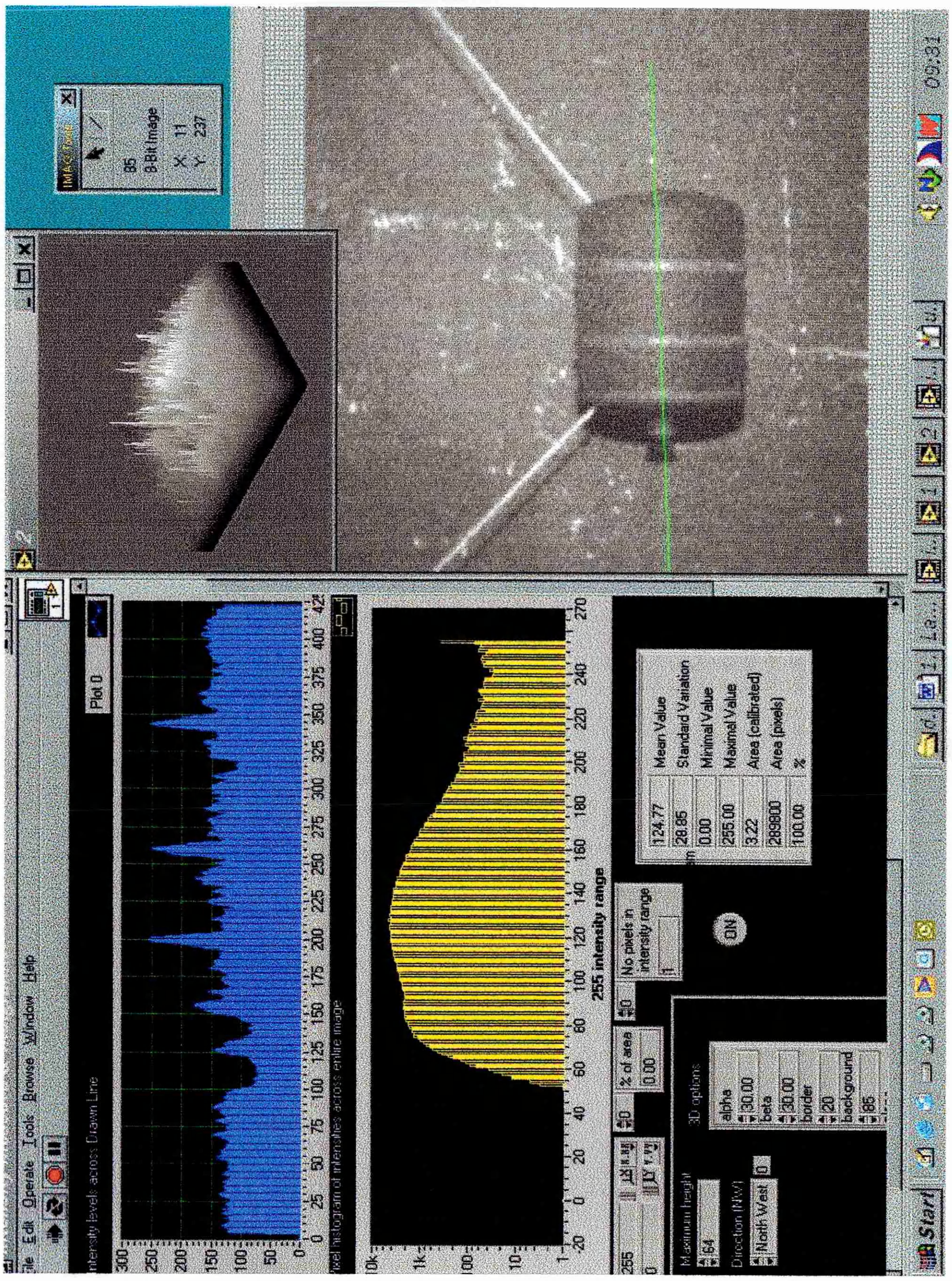


Figure 9.1: Analysis algorithm; 'Intensity measure and histogram.vi' operator interface. (Analysis if a lamp image at 3.5m (clear water))

10 RESULTS

As turbidity increases it has been discussed that noise creates a greatest challenge to any process of stripe isolation. During this research project several techniques were developed to perform this isolation and to compile an image of a target object from the isolated and extracted regions.

Thus efficient stripe isolation can be considered a primary goal in the algorithm development. It was noted that due to the nature of laser stripe projections there is a limited amount of visual information that can be extracted from an image of a laser stripe as it falls upon a target object. The ability of the developed algorithms to offer improved object identification and recognition can be defined through its ability to use this available visual information to offer the best possible results to the operator. Realistically this can only be achieved through direct visual comparison of images. Beyond this it is only possible to assess a method by breaking the processing down into the success of its component parts. With respect to the algorithms developed this can only correctly conducted through testing of the ability of the algorithm to isolate the stripe.

With the use of the analysis algorithm, this was performed by assessing individually processed stripes and comparing their efficiency in the removal of all pixel information outside of the stripe region. A correctly isolated stripe should produce a black image with all visual information removed apart from that of the stripe region itself. This aim is increasingly challenged as turbidity in the medium rises and noise increases with stripe definition decreasing.

The results of the algorithm tests are displayed in two parts: Part 1 involved the comparison of the appropriate data obtained as individual processed stripe images were passed through the analysis algorithm. Part 2 is the display of processed stripe images and complete target images captured during processing. These are presented across increasing turbidity conditions. The use of arc lamp images as a comparison is carried out where such images were obtainable within the subject conditions.

10.1 'LASER STRIPE 1A.VI'

This algorithm was based on the inclusion of temporal differencing and thresholding techniques to perform the isolation of the stripe region. The effects of applying temporal differencing to the stripe were shown earlier and illustrated the aptitude of the technique to reduce backscattering noise. This though was limited and primarily served to improve stripe definition. Effective isolation was conducted through the operator control of the threshold range.

To assess the usefulness of this control, processed stripe images were captured at a range of 3.5m, in clear water (average NTU reading = 0.103) and with the addition of 60g of bentonite (average NTU reading = 0.479) to the tank. The upper threshold range was held at a constant and the lower threshold range increased progressively until the stripe image was effectively lost. These images were passed through the analysis programme to obtain a percentage value of the image equating to black or 0 pixel intensity. This would illustrate firstly the ability of the technique to reduce the isolated region and secondly by comparison of the results over the different conditions to outline altering behaviour or trends over increased turbidity. Figure 10.1 displays the results of this analysis.

These results can be compared to table 10.1 which displays values for the percentage of pixels across unprocessed stripe images that contain intensity values of 0.

Bentonite Measure	**Clear Water**	**20g**	**40g**	**60g**
% of Pixels = 0	0.01	0	0	0

Table 10.1: Percentage of unprocessed stripe images equalling 0 pixel intensities

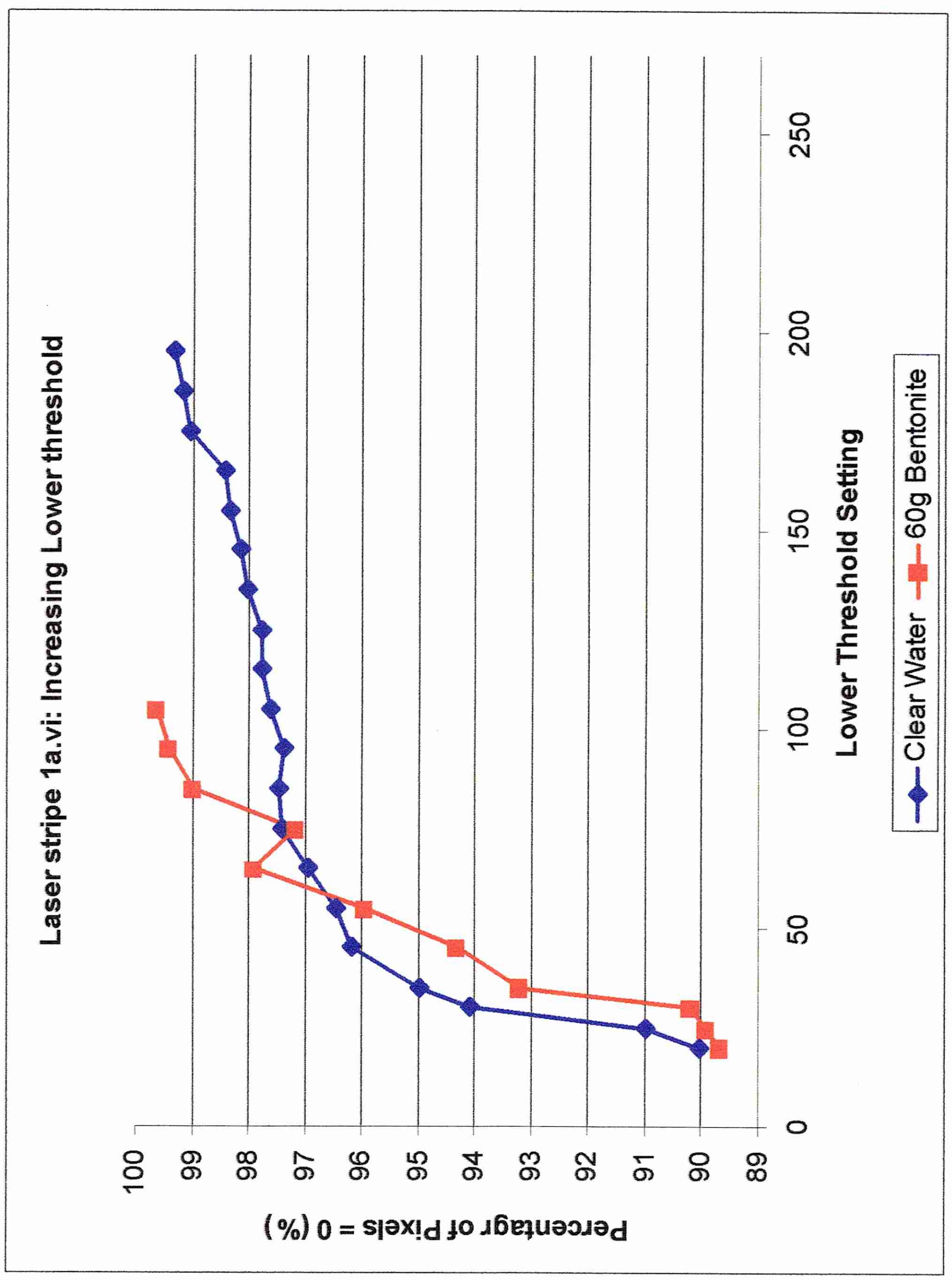


Figure 10.1: 'Laser stripe 1a.vi': Increasing lower threshold.

Referring to figure 10.1, with the upper threshold held at a constant value of 255, the effect of progressively increasing the lower threshold limit is to progressively increase the percentage of pixels across an image with a value equal to zero, Which is to be expected. Data recordings in higher turbidity though show a somewhat more erratic nature than the smoother curve representing samples taken in clear water. Comparison of clear water sample images and 60g bentonite samples show a close trend prior to stripe loss. The loss of the stripe is experienced at an earlier stage in higher turbidity than in samples taken through clear water.

The earlier loss of the stripe at a lower threshold limit of 105 in higher turbidity is due to a larger proportion of the image falling within lower intensity regions and signifies the increased proportion of the image represented by scattering events. The effect of the temporal differencing is to reduce a large proportion of the pixel intensities during the subtraction process. The smoother progression expressed by the clear water data is due to the less erratic nature of the medium in which the images were captured. It should be noted that it is not possible to capture a stripe in precisely the same position through this method as the temporal differencing requires a scanning stripe to achieve an image.

The trends shown by increasing the lower threshold are much to be expected, effectively removing pixels of low intensity from the image and in doing so increasing the area of the image equalling black. These results do show an effective ability to reduce the isolated area of the image within the boundaries of the threshold range. It must be recognised though that this may not all be due to unwanted noise, but may be the result of loss of stripe projection over the curvature of the target. When compared to the unprocessed stripe data displayed in table 10.1, it can be seen that approximately 90% of the pixel intensity values of the images fall within 0 and 20. This though is achieved after temporal differencing is applied. By analysis of an unprocessed stripe captured in clear water it is possible to see more clearly the intensity range across the image prior to temporal differencing application.

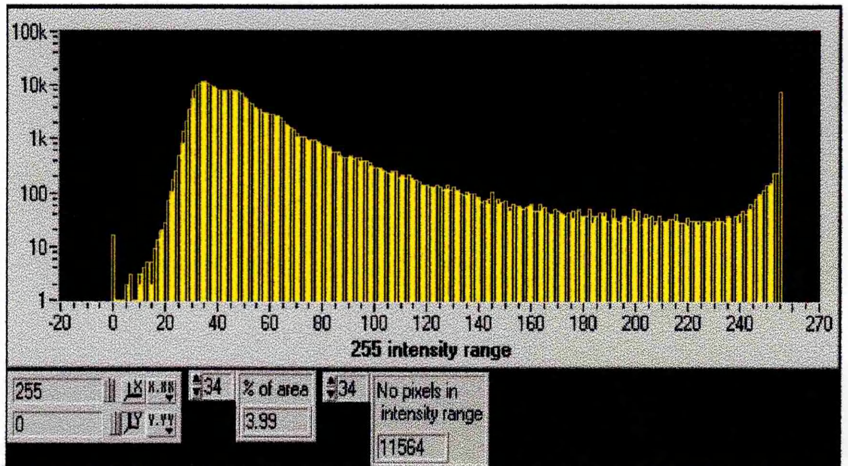
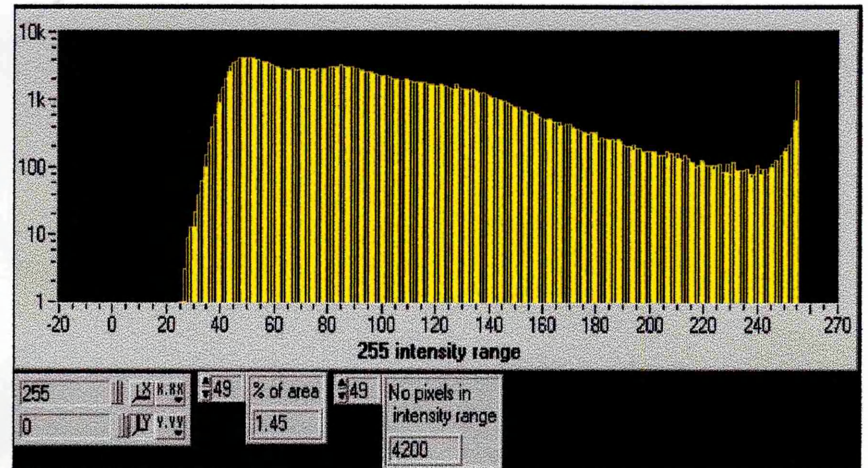


Figure 10.2: Clear Water Image Intensity graph



Graph 10.3: 60g Bentonite Addition Image intensity graph

Figures 10.2 and 10.3: Intensity graphs across the unprocessed clear water stripe image and stripe image with the addition of 60g of bentonite

The intensity graphs across the images show that prior to the application of the temporal differencing technique the intensity values are spread across the range. Peaks are experienced at 255 predominantly around the stripe region and in the mid 30s range. In clear water the percentage of pixels falling into intensities below 20 was found to be only 2.64%

Obtaining a graph from an unprocessed stripe captured after the addition of 60g of bentonite, peaks can be seen in the high 40s and once again at 255. The percentage of pixels falling below a value of 20 for intensity is 0. Thus it can be seen then that the inclusion of the temporal differencing technique causes a sizable shift in the intensity values of pixels across the image. This characteristic is valuable for the isolation of the stripe, but is detrimental if a noticeable loss of intensity is experienced over the stripe region itself.

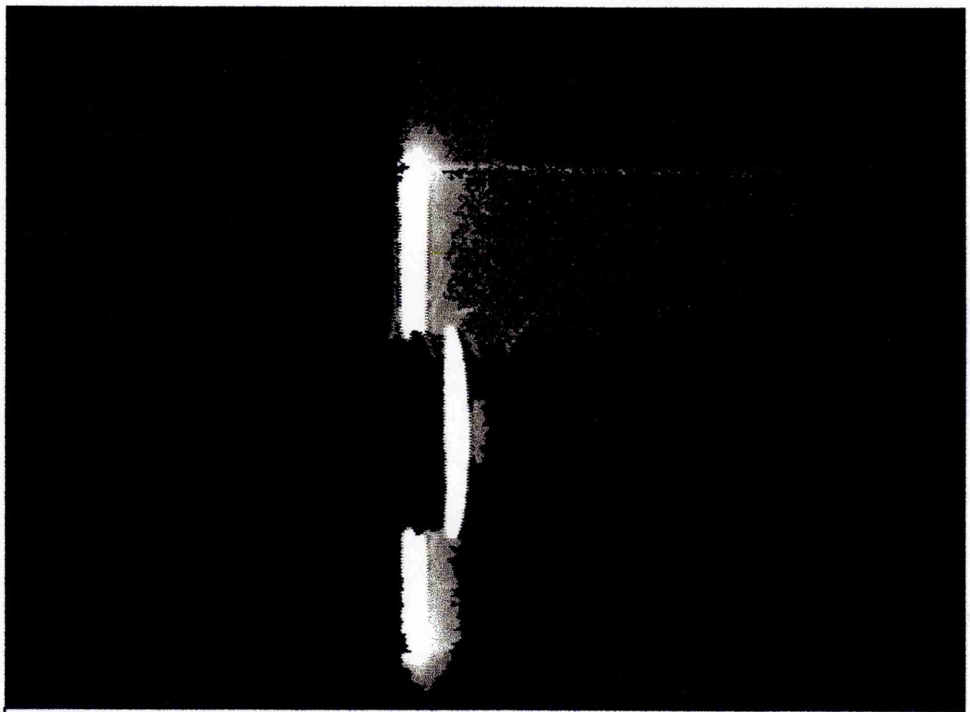
It is possible to examine the effect of temporal differencing on the stripe region through data taken from the analysis algorithm. Taking that the brightest pixel intensities are primarily stripe information, the proportion of the image holding a value of 255 can be obtained and compared to corresponding data from unprocessed stripe grabs. This comparison can be seen in table 10.2 with processed stripe threshold range set to 20 to 255.

Bentonite measure	**Clear Water**	**20g**	**40g**	**60g**
Unprocessed images	2.61%	1.85%	1.06%	0.66%
Processed images	1.32%	1.05%	0.61%	0.04%
Percentage shift	1.29%	0.80	0.45	0.62

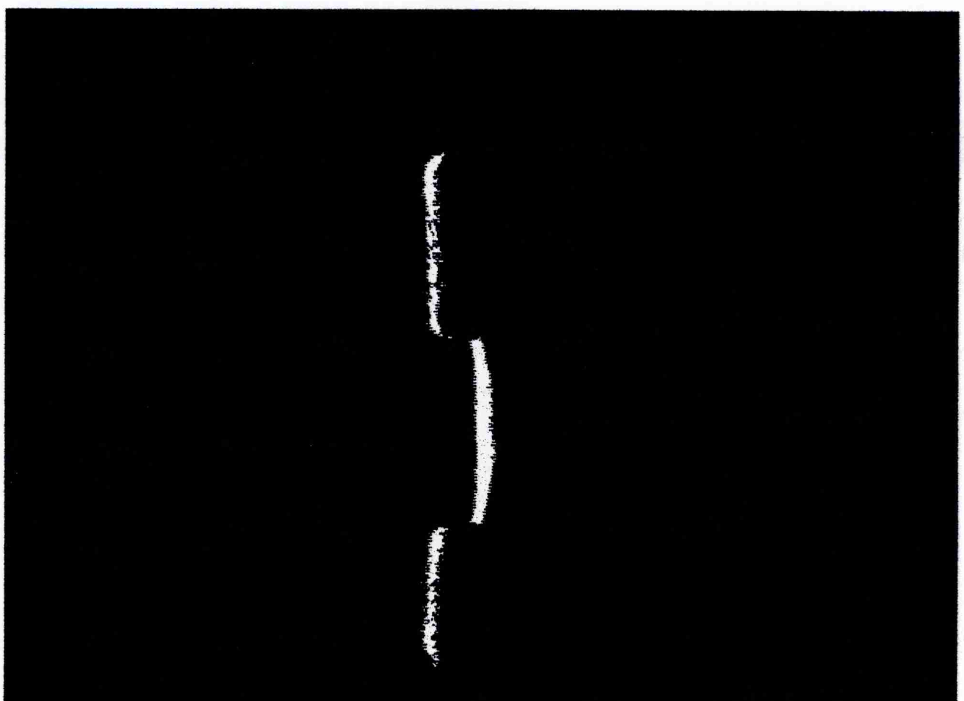
Table 10.2: Percentage of pixels across total image equal to 255 intensity.

The shift in percentages illustrate that the temporal differencing technique does not only remove much of the backscatter but also degrades the brighter pixel values. This confirms that subtracting the previously captured image may result In valuable stripe information being degraded or lost. It is by no means certain that this shift is purely within the stripe and may include the reducing of particularly bright backscatter that may occur in the image. However a general reducing of intensity values across the image can be shown thus lessoning the importance of visual information available through intensity variance across the stripe. The temporal differencing may also have an effect in extreme cases of reducing stripe definition

Figures 10.4 and 10.5 below takes two images used during the clear water and 60g bentonite analysis to allow a visual comparison of the effect on the isolated stripe region. The images shown are taken at extremes of the testing range prior to stripe loss.

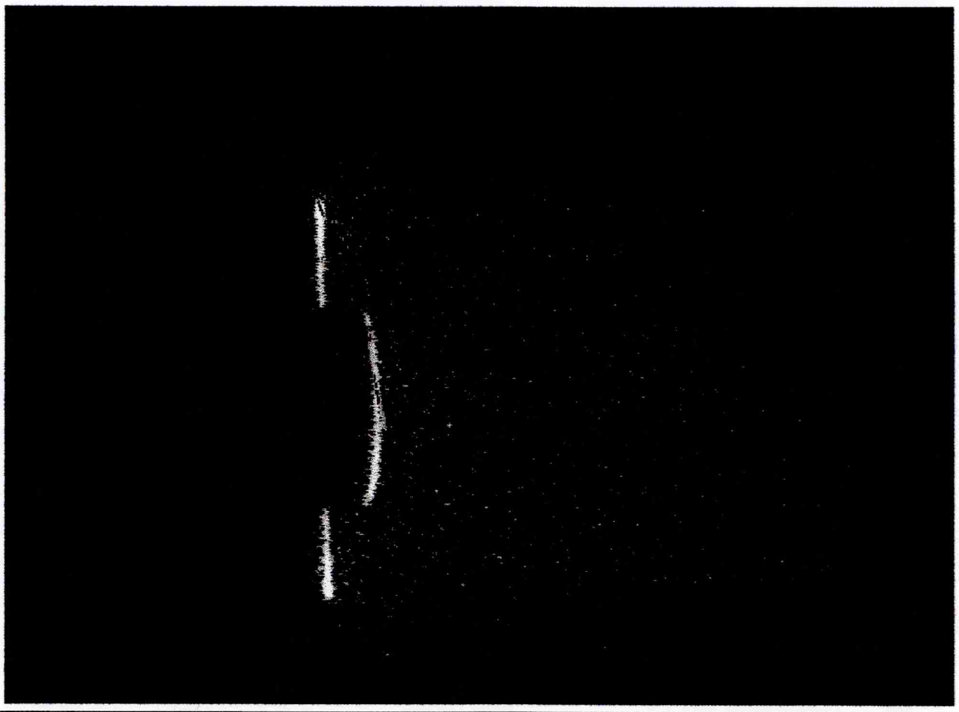


Clear Water; Threshold range 20 to 255

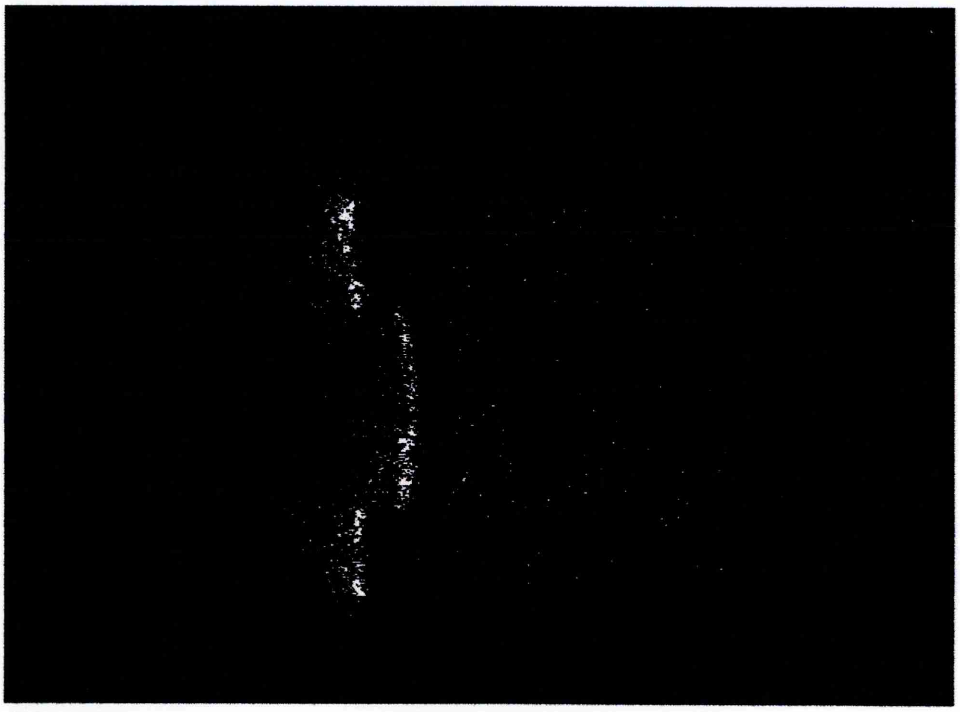


Clear Water; Threshold range 165 to 255

Figure 10.4: Comparison of processed stripes in clear water



60g Bentonite; Threshold range 40 to 255



60g Bentonite; Threshold range 80 to 255

Figure 10.5: Comparison of processed stripes in turbid water

These comparison images shown, clearly illustrate that increasing the lower intensity limit in clear water removes unwanted visual information efficiently, whilst holding the relative integrity of the stripe. In turbid conditions though a larger proportion of the stripe falls within the lower intensity range as can be seen from the degradation of the stripe itself. This is due to more than one aspect of scattering: Firstly, the increase in turbidity results in greater scattering events appearing within the region of the stripe resulting in lower intensity reflections. Secondly the intensities of reflections received from the stripe are being degraded by scattering events on their return to the camera. There is also the issue of the efficiency of the temporal differencing technique as greater levels of scattering will result in lower intensity imaging of the stripe.

10.2 'MINIMAL GAMMA 1.VI'

Based on the use of lookup tables 'Minimal Gamma 1.vi' enabled control of the isolation process by increasing the gamma coefficient (γ) through the operator interface. As described previously, the gamma coefficient defines a lookup table by which intensity values are converted. Higher intensity pixels are raised in value whilst lower intensity values are diminished.

To assess the worth of this control, processed stripe images were captured over a range of gamma coefficient values from the default value of 1, through to 8, with the progressive addition of bentonite in 20g increments and analysed as before. Figure 10.6 displays the results of this analysis.

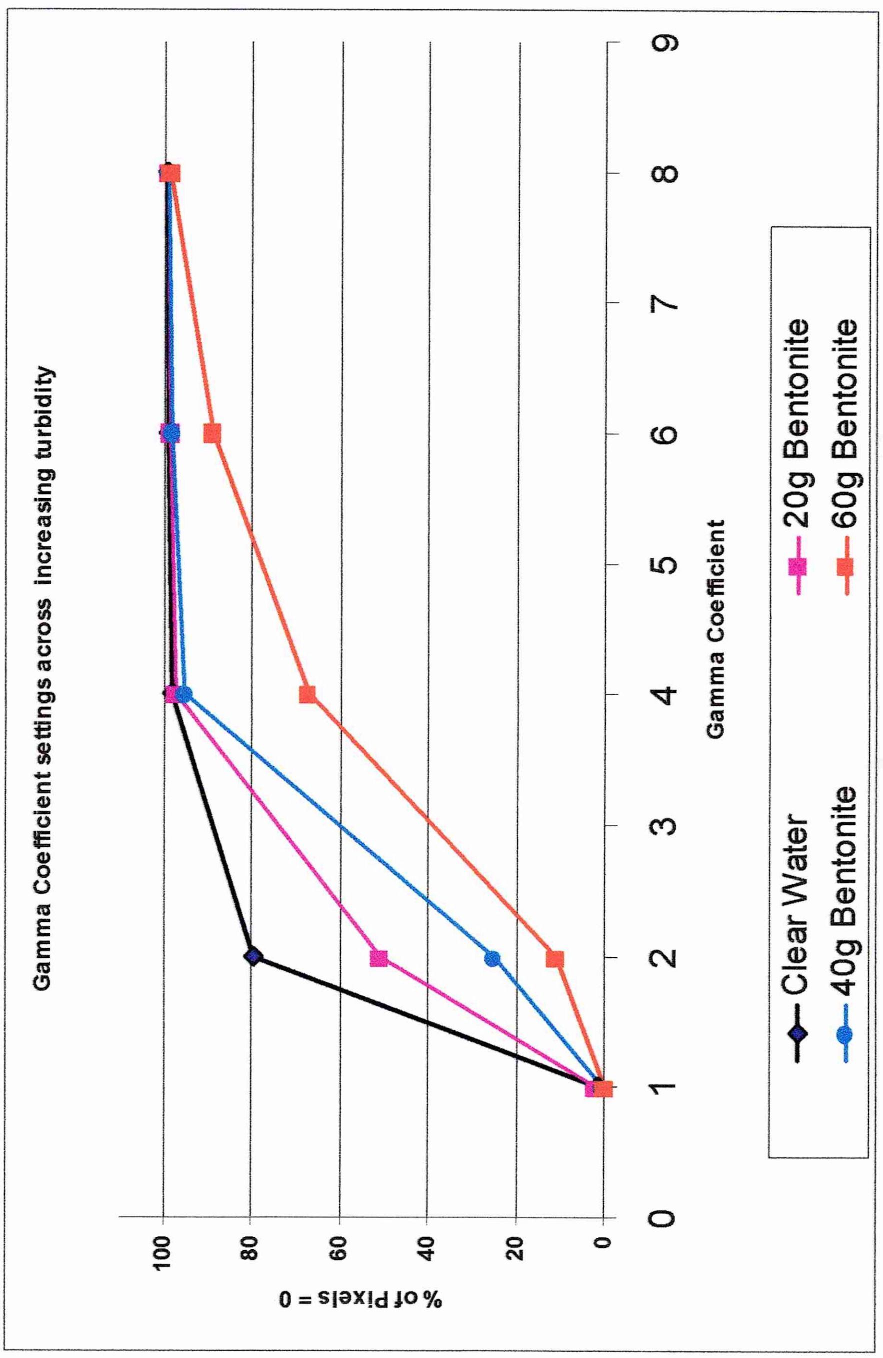


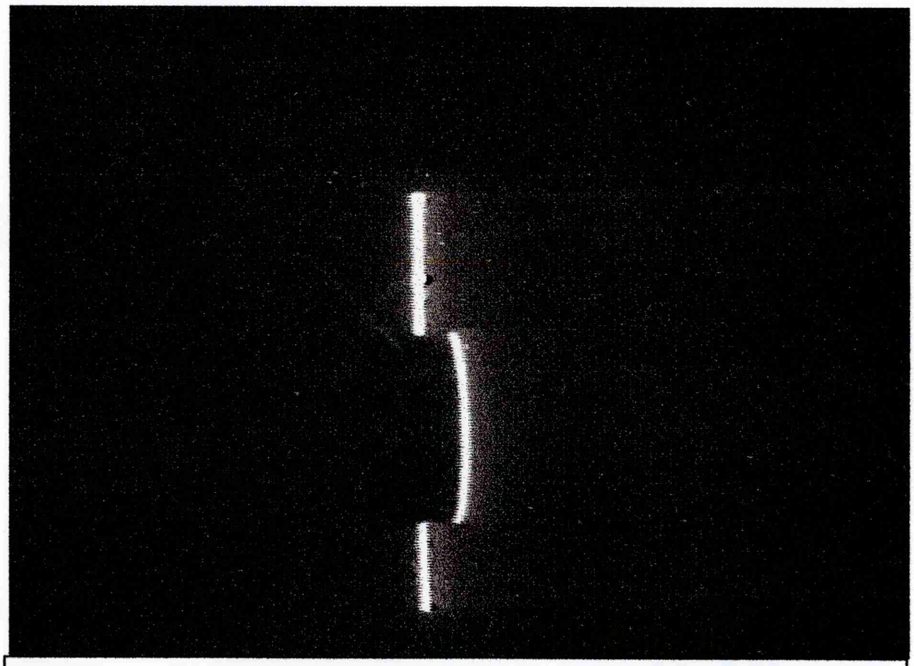
Figure 10.6: 'Minimal Gamma 1.vi': Increasing gamma coefficient.(Y)

Referring to figure 10.6, the progressive increase in the gamma coefficient value (Y) results in an increase in the efficiency of the isolation of the stripe region. This though is at the expense of useful visual information obtainable through pixel intensity variance.

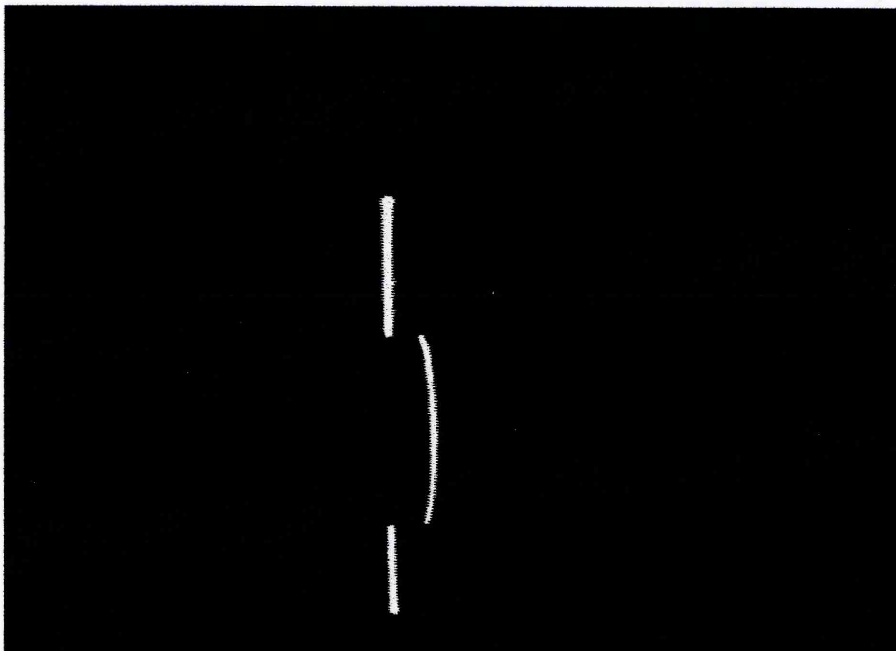
When comparing these results with figures 10.7 and 10.8, close examination of the images obtained across the range, indicate that the isolation of the stripes in clear water, 20g and 40g of bentonite (average NTU readings of 0.103, 0.287 and 0.421 respectively) are effectively achieved with a gamma coefficient of 4. Thus alterations in pixel intensities can be minimised at this level, in these conditions. With the addition of 60g of bentonite (average NTU readings of 0.479) however, this relationship alters. 60g of bentonite achieves relative stripe isolation at a gamma coefficient of 8 requiring an increased level of pixel intensity alterations.

One impediment to the effective compilation of target images with raised turbidity, is the loss of classifiable visual information relating to the reflective properties of the object. Therefore the use of a higher gamma coefficient, and so the greater alteration of pixel intensities would not necessarily result in loss of useful visual information obtainable through any intensity variation across the stripe.

The following figures display stripe images captured through clear water and the addition of 20g increments of bentonite to the tank. In each case an image is displayed of the captured image with a gamma setting of 1 (default setting) alongside the image captured at a gamma setting equating to the effective isolation of the stripe region from backscatter.

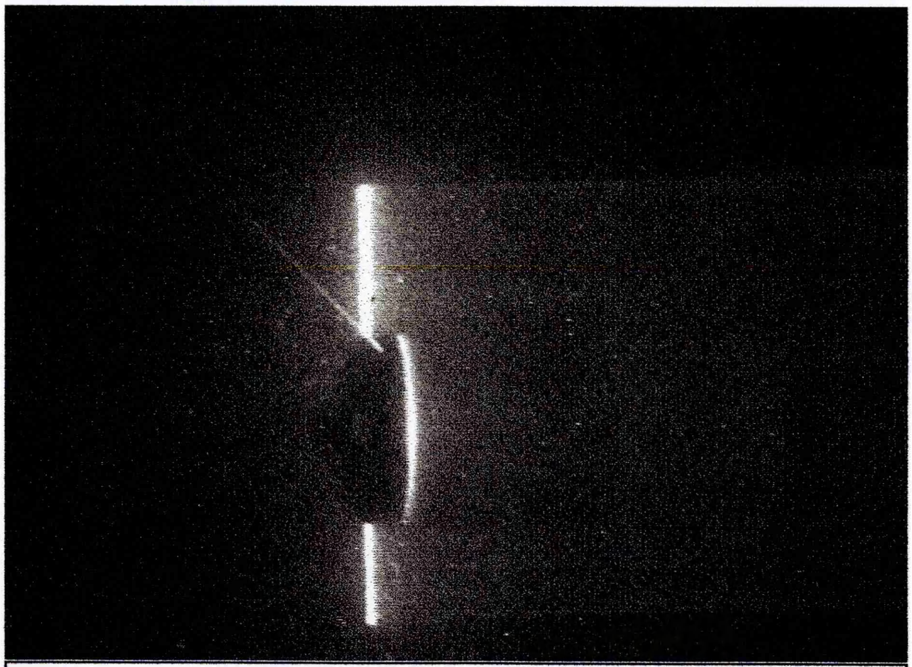


Gamma coefficient = 1 (default)

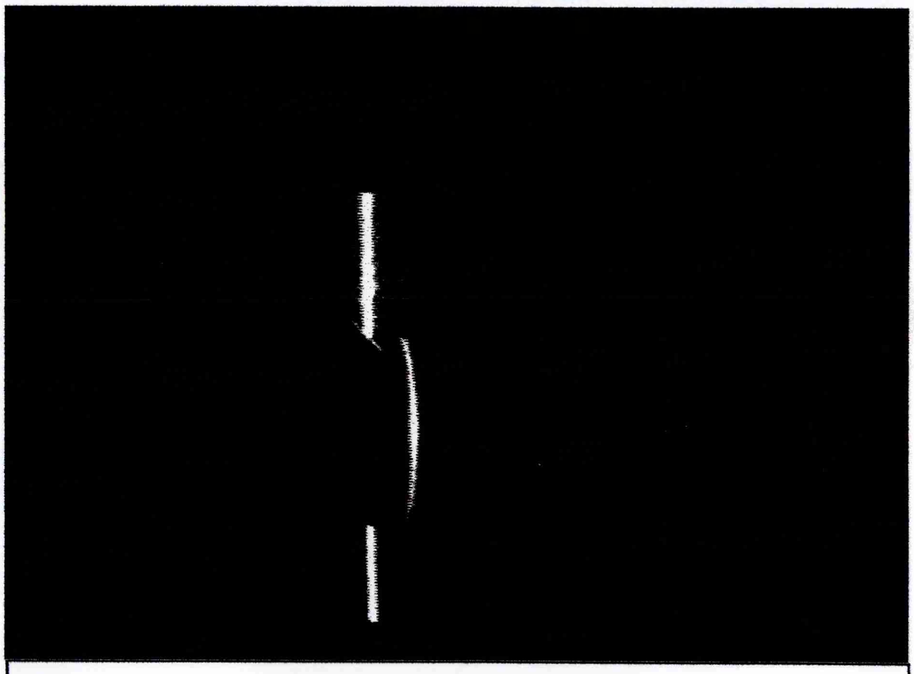


Gamma coefficient = 4

Figure 10.7: 'Minimal Gamma 1.vi': Clear water comparison images



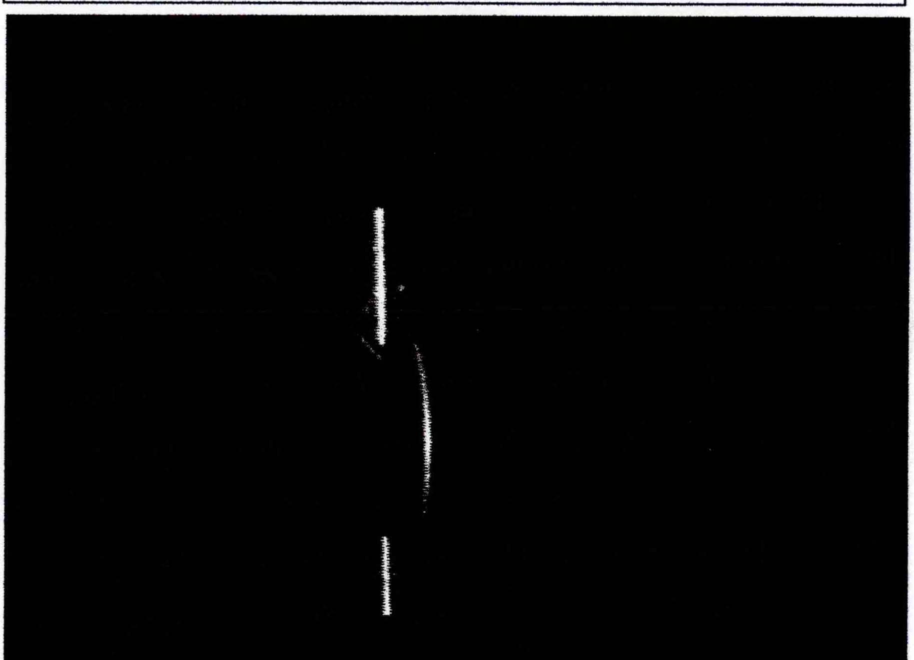
Gamma coefficient = 1 (default)



Gamma coefficient = 4

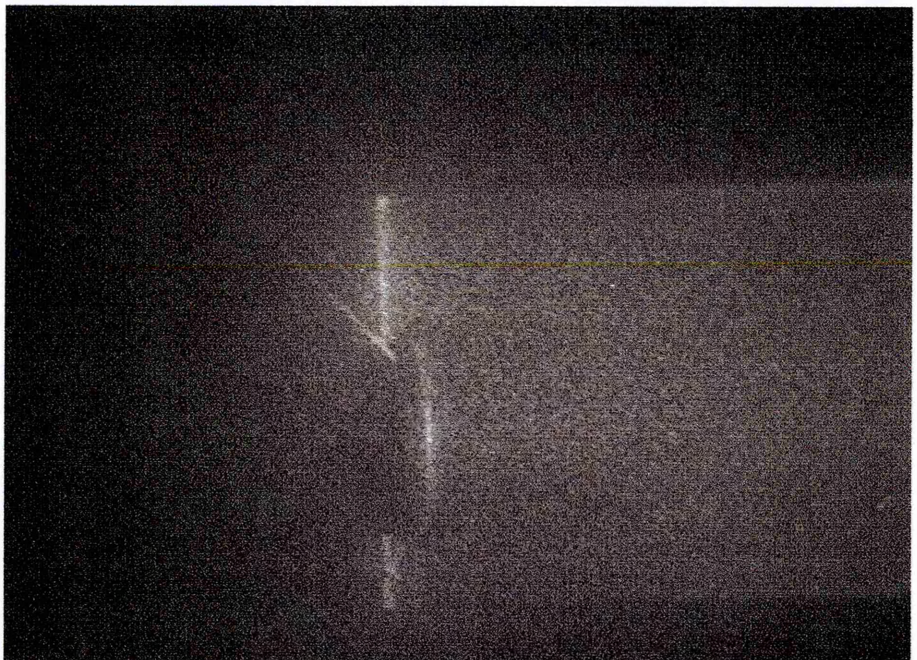
Figure 10.8: 'Minimal Gamma 1.vi': 20g Bentonite, comparison images

Gamma coefficient = 1 (default)

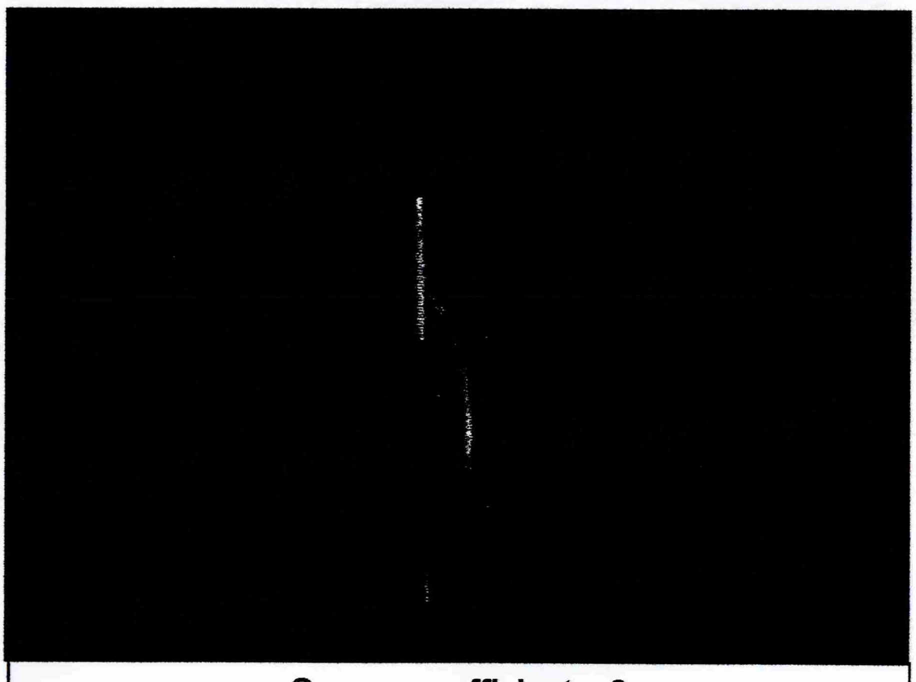


Gamma coefficient = 4

Figure 10.9: 'Minimal Gamma 1.vi': 40g Bentonite, comparison images



Gamma coefficient = 1 (default)



Gamma coefficient = 8

Figure 10.10: 'Minimal Gamma 1.vi': 60g Bentonite, comparison images

Gamma coefficient = 1 (default)

Gamma coefficient = 8

Figure 10.11: 'Minimal Gamma 1.vi': 80g Bentonite, comparison images

10.3 'MINIMAL GAMMA 1 WITH POPEN FILTER'.VI'.

The Proper opening greyscale filter was added to the 'minimal gamma' vi, primarily to test the affects that the erosion, opening and proper opening filters would have upon a processed stripe. Under conditions of raised turbidly degradation of the stripe can be seen and this filter not only helps to enhance intensity alteration patterns seen across an image but also has the effect of smoothing an irregular edge.

No direct control is provided to the filter which was purely included as a support function for the gamma correction. Thus testing of the inclusion of the filter as an extension of the results obtained from the 'minimal gamma 1'.vi. Therefore the results were obtained under precisely equivalent conditions and are presented in figure 10.12.

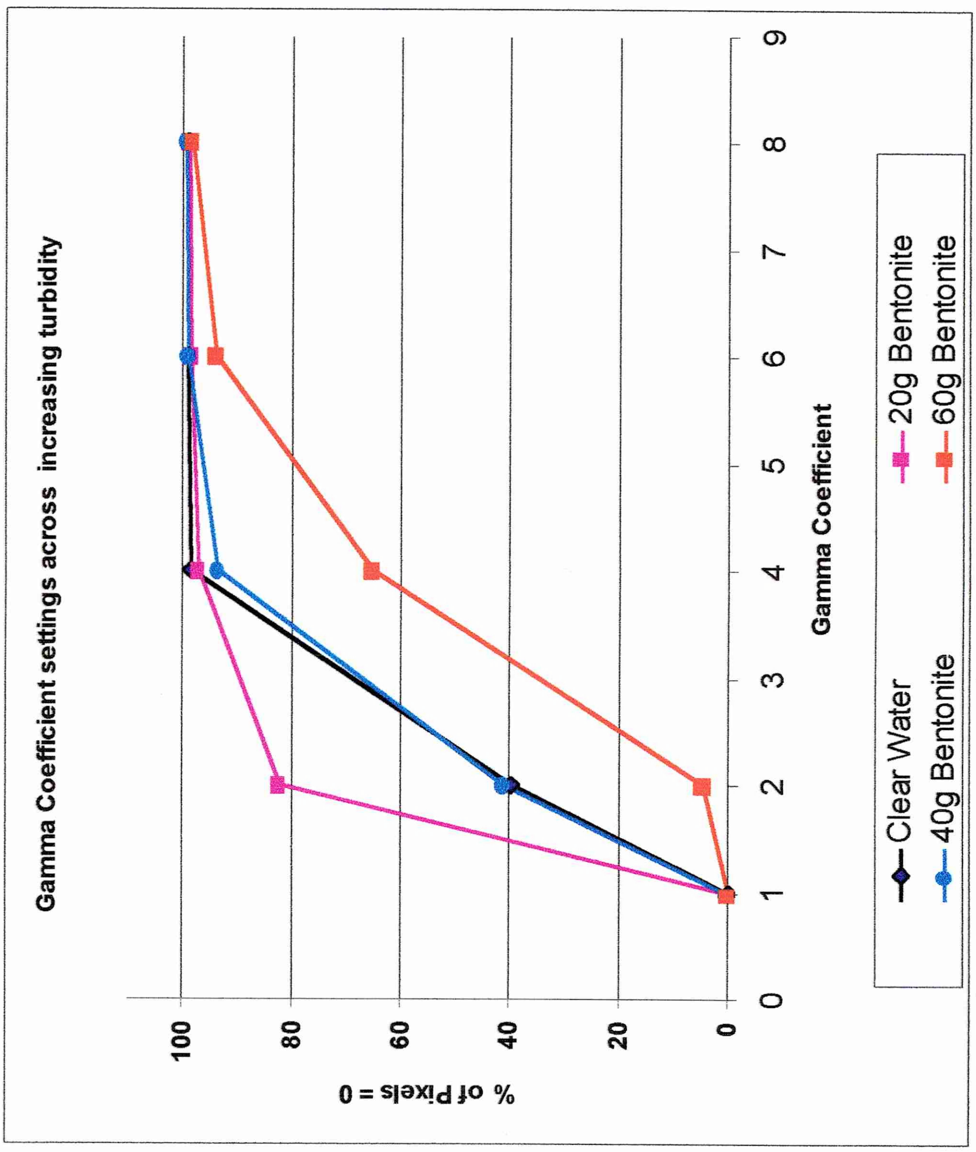


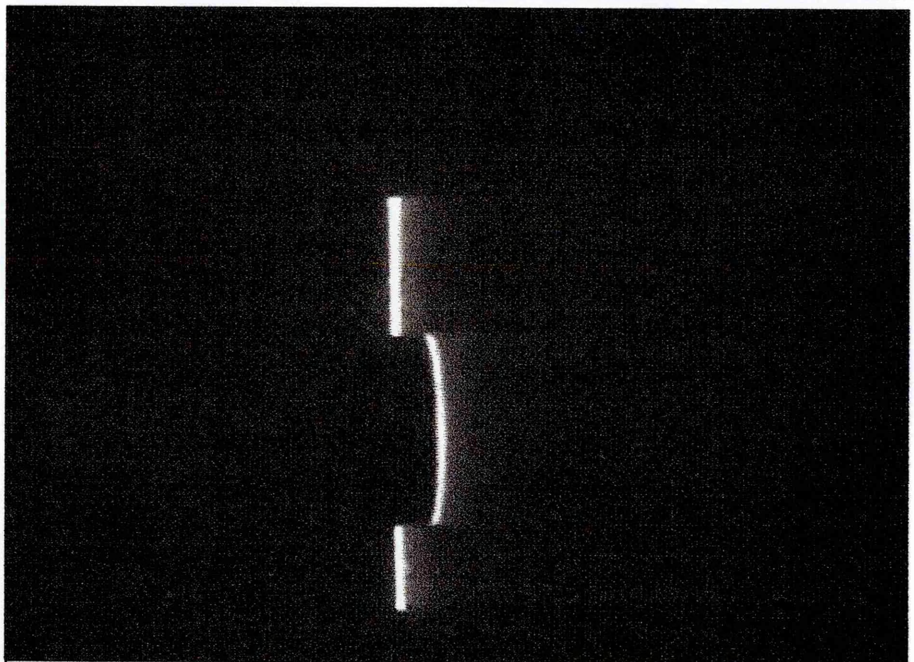
Figure 10.12: 'Minimal Gamma 1 with POPEN filter.vi': Increasing gamma coefficient(Y)

10.4 DISCUSSION

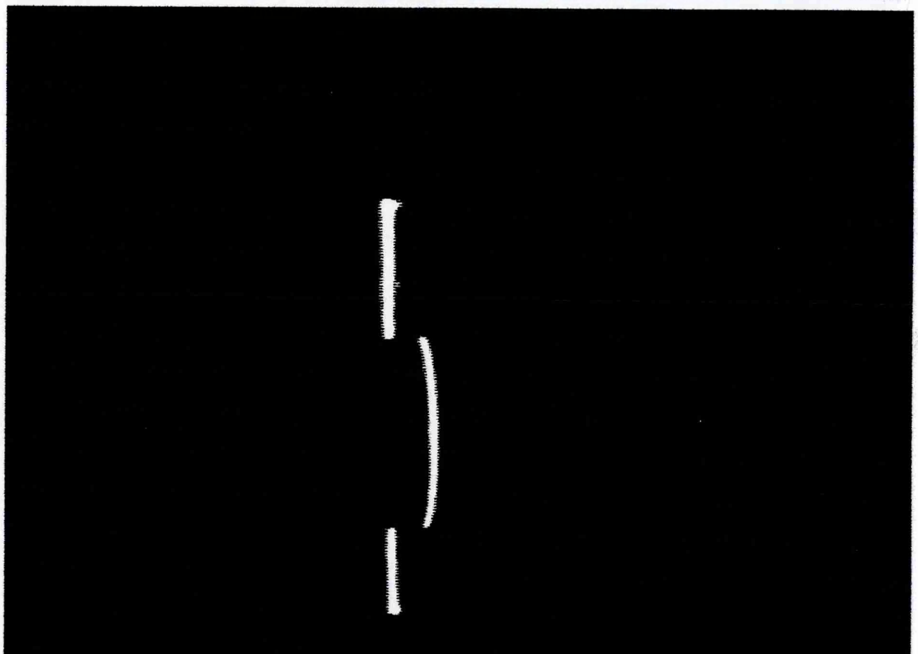
The most noticeable characteristic of this graph in comparison to the gamma correction data is that the 20g bentonite readings correspond very closely to the clear water data gained with gamma correction on its own. This raised initial jump from 0 to 82.14% pixels equal to 0 is complemented by the reduction of the clear water data which shows a considerably reduced initial jump between gamma 1 and gamma 2. At 40g bentonite there is also a raised initial jump on a lesser scale whilst the 60g bentonite readings demonstrate a lower initial rise than that experienced through the unaccompanied gamma correction. The gamma settings at which efficient stripe isolation can be achieved remain the same.

As a result, the affect of adding the filter can clearly be seen. Brighter pixels are removed from the images enhancing the affect of the gamma correction. As turbidity increases, its affect is diminished; this is due to fewer occurrences of brighter pixels. The overall affects of this are greater adjustments to the intensity variance across the stripe region in lower turbidity.

The following figures display stripe images captured through clear water and the addition of 20g increments of bentonite to the tank. In each case the default gamma setting is shown alongside the image captured at the gamma setting equating to effective stripe isolation.

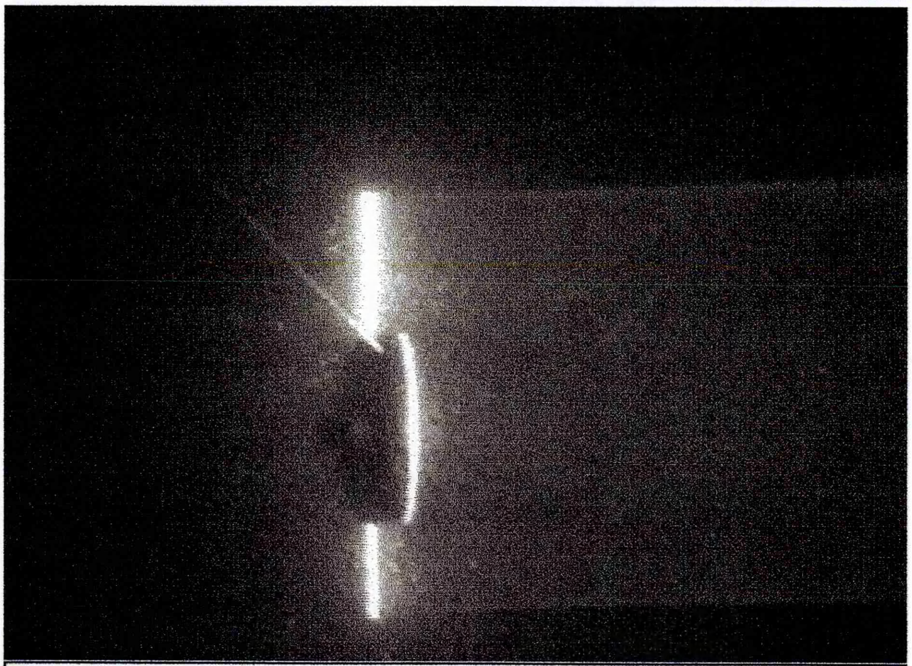


Gamma coefficient = 1 (default)

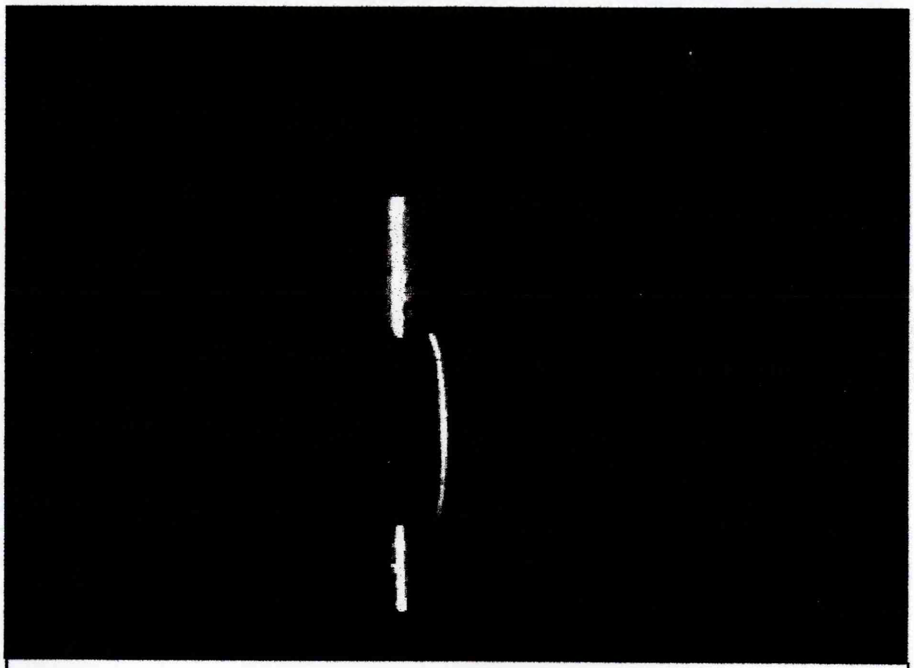


Gamma coefficient = 4

Figure 10.13: 'Minimal Gamma 1 with POPEN filter.vi': Clear Water, comparison images

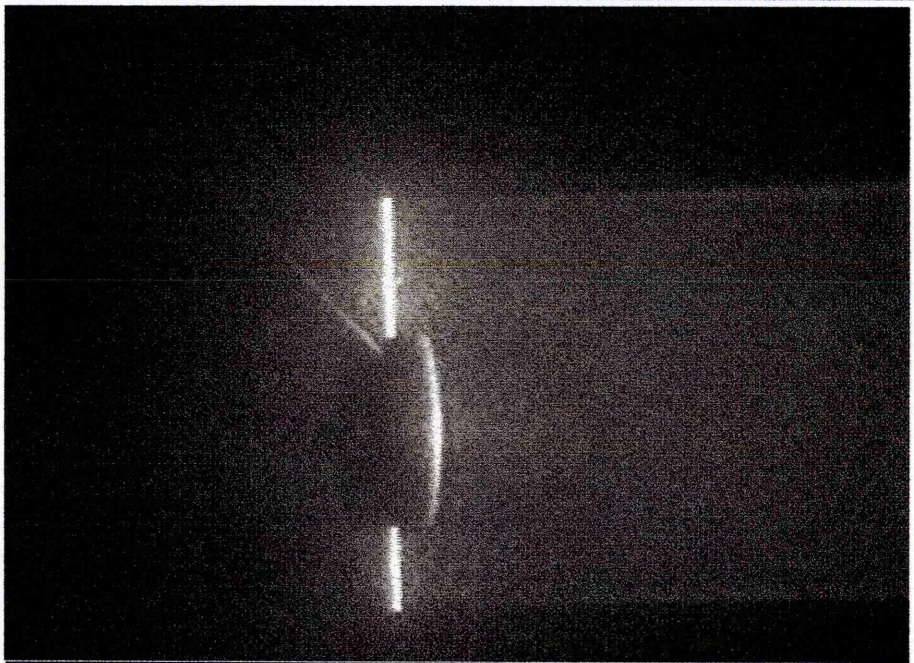


Gamma coefficient = 1 (default)

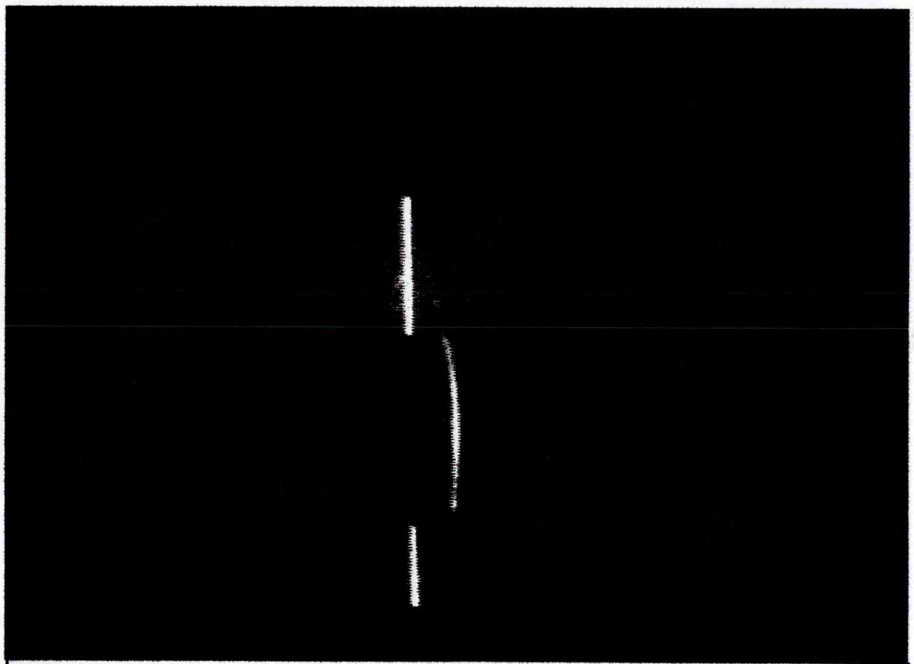


Gamma coefficient = 4

Figure 10.14: 'Minimal Gamma 1 with POPEN filter.vi': 20g Bentonite, comparison images



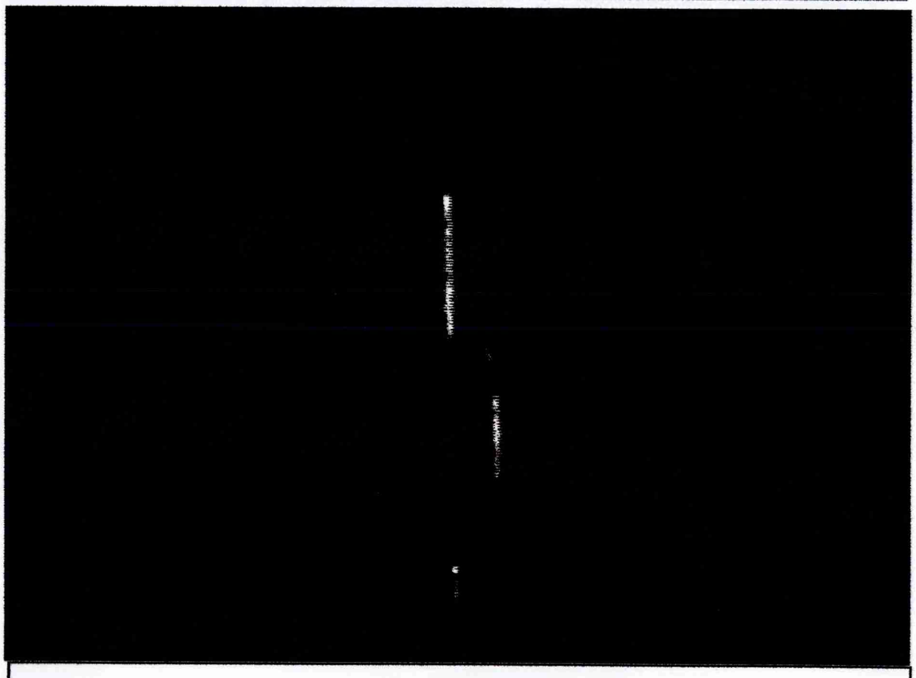
Gamma coefficient = 1 (default)



Gamma coefficient = 4

Figure 10.15: 'Minimal Gamma 1 with POPEN filter.vi': 40g Bentonite, comparison images

Gamma coefficient = 1 (default)



Gamma coefficient = 8

Figure 10.16: 'Minimal Gamma 1 with POPEN filter.vi': 60g Bentonite, comparison images

Visual comparison of the effect of the inclusion of the Proper-opening filter was inconclusive from these images, but the smoothing of the edges can be seen to a small extent in the clear water images. It is understandable that inspection by the naked eye is ineffective as changes to the image are minute. It could therefore be assumed that the value of adding the filter to the algorithm is limited. This is emphasised by the results displayed in graph 10.12 which shows the effect of this filter to be an increase in alterations in pixel intensities where it has been shown through the use of gamma correction on its own is effective.

10.5 DIRECT COMPARISON OF IMAGES

The analysis of individual processed stripes can only serve to partly asses the individual components of the algorithms. Definitive testing though must be assessed through the capture of cumulative images over the range of a target object. This is best conducted through the visual comparison of images obtained of a standard target object over a consistent range.

Figures 10.17 to 10.21 show the target barrel imaged over 3.5m in increasingly turbidity conditions ranging from clear water to 80g bentonite addition equating to an average NTU readings of 0.103 to 0.579. In each example a lamp image is included and compared against the interpretation available over 1 scan of the target through 'laser stripe1a.vi' using the temporal differencing and thresholding techniques, and through 'Minimal gamma 1.vi' using gamma correction alone.

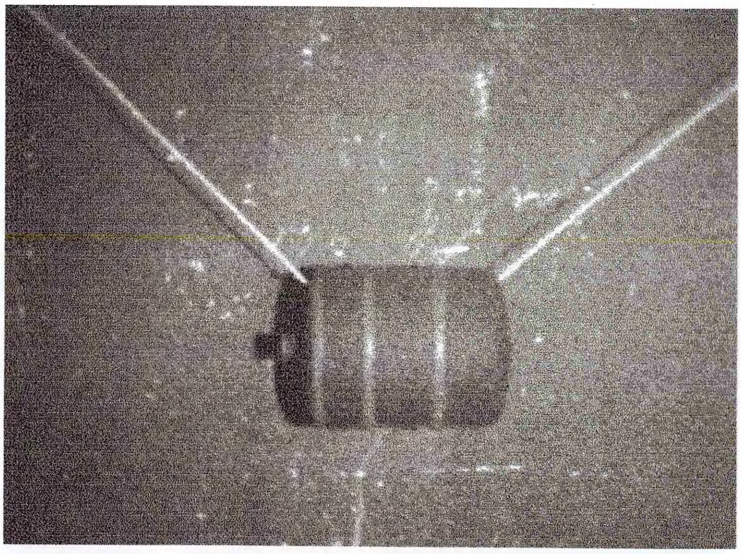
The description of each image includes data for processing time in terms of the number of stripes grabbed per second (p/s) along with the threshold range or gamma coefficient applied.

Lamp Image

Range
= 3.5m

Clear Water

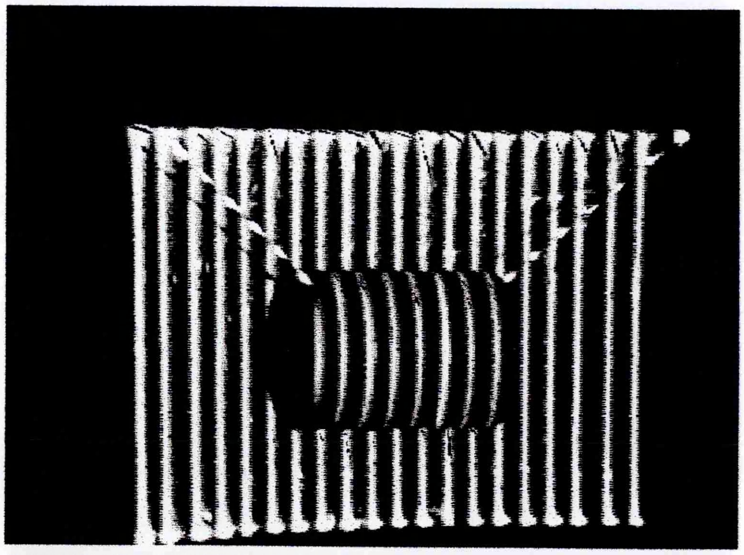
Average NTU
Reading
= 0.103



Laser Stripe 1a.vi

2 stripes p/s

Threshold range
= 75 - 255



Minimal
gamma 1.vi

3-4 stripes p/s

Gamma setting
= 6

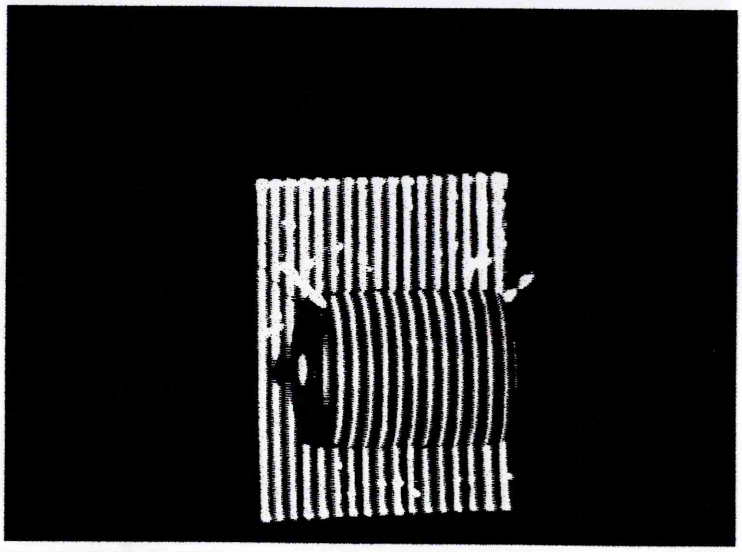


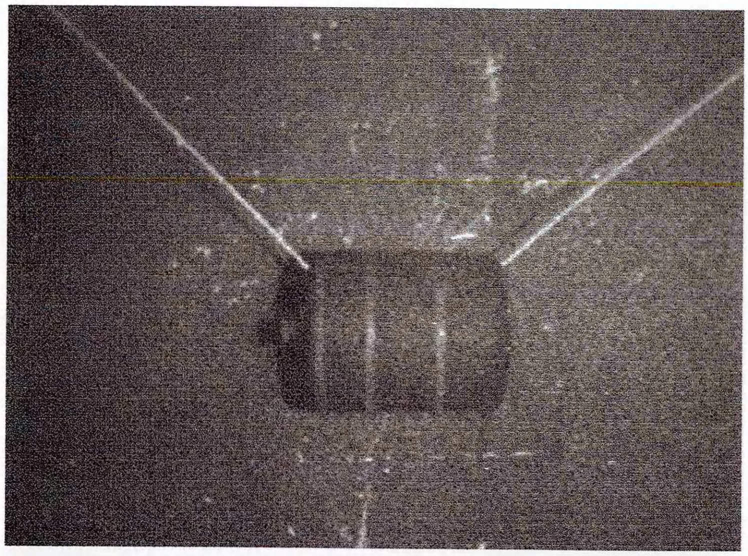
FIGURE 10.17: Barrel target images at 3.5m range in clear water

Lamp Image

Range 3.5m

Bentonite measure = 20g

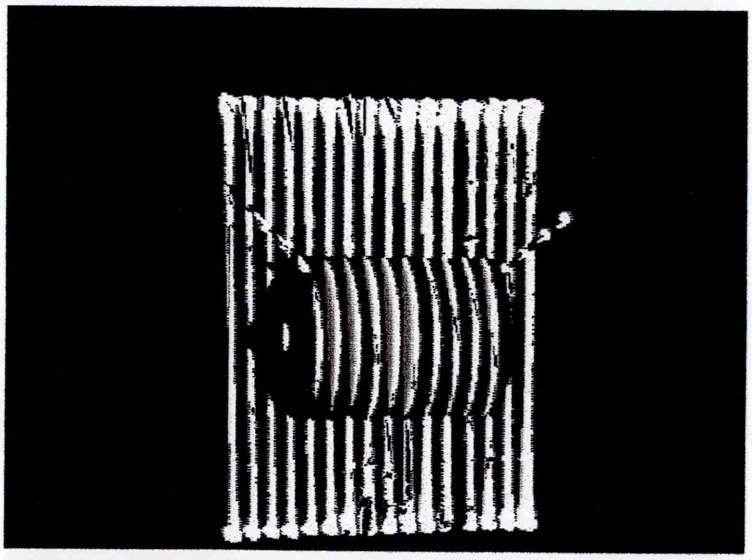
Average NTU Reading = 0.287



Laser Stripe 1a.vi

2 stripes p/s

Threshold range = 165 - 255



Minimal gamma 1.vi

3-4 stripes p/s

Gamma setting = 6

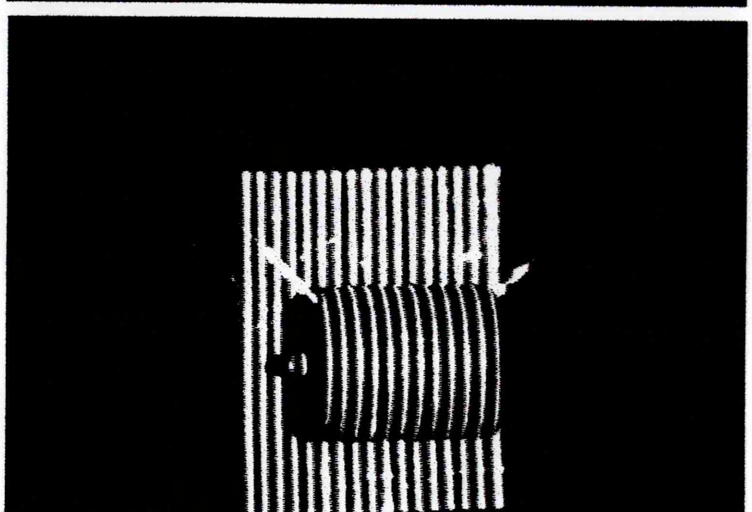


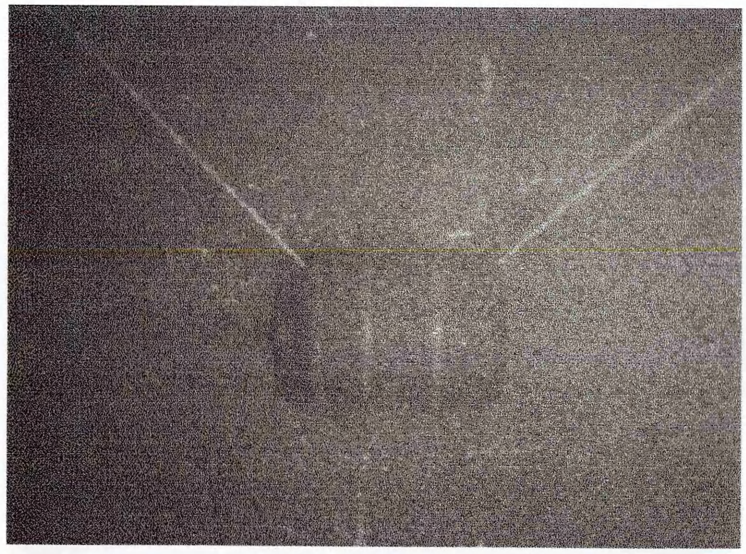
FIGURE 10.18: Barrel target images at 3.5m range with 20g bentonite addition

Lamp Image

Range 3.5m

Bentonite measure = 40g

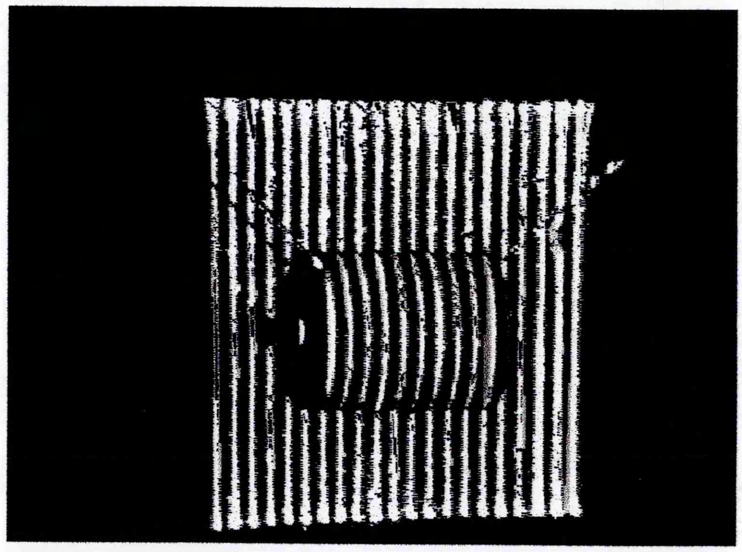
Average NTU reading = 0.421



Laser Stripe 1a.vi

2 stripes p/s

Threshold range = 105 - 255



Minimal gamma 1.vi

3-4 stripes p/s

Gamma setting = 6

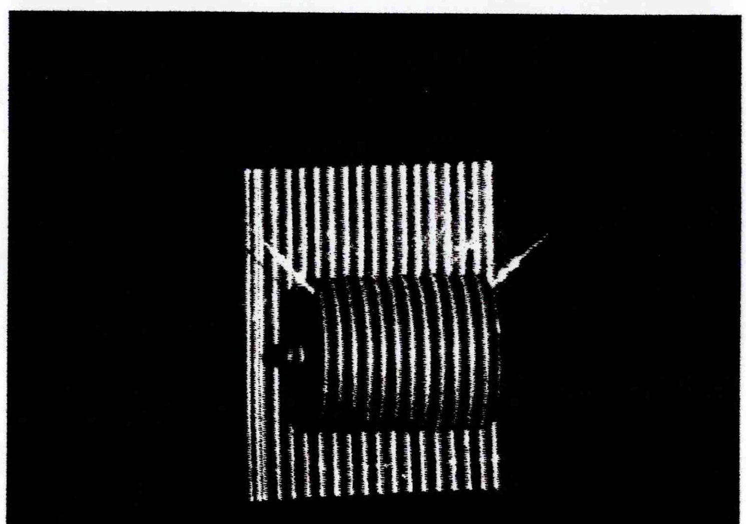


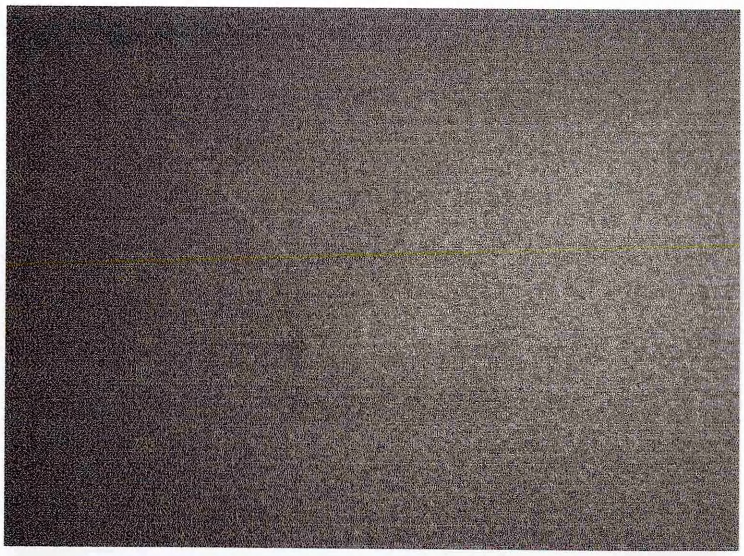
FIGURE 10.19: Barrel target images at 3.5m range with40g bentonite addition

Lamp Image

Range
3.5m

Bentonite
measure
= 60g

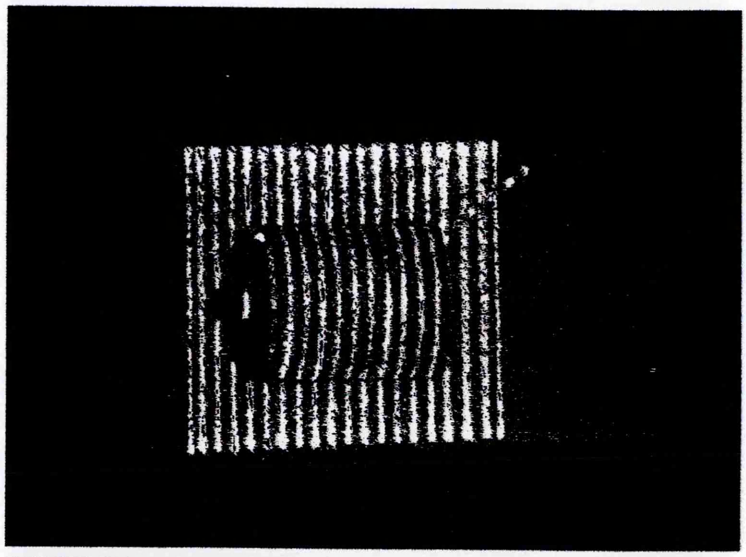
Average NTU
reading
= 0.479



Laser Stripe 1a.vi

2 stripes p/s

Threshold range
= 80 - 255



Minimal
gamma 1.vi

3-4 stripes p/s

Gamma
setting
= 8

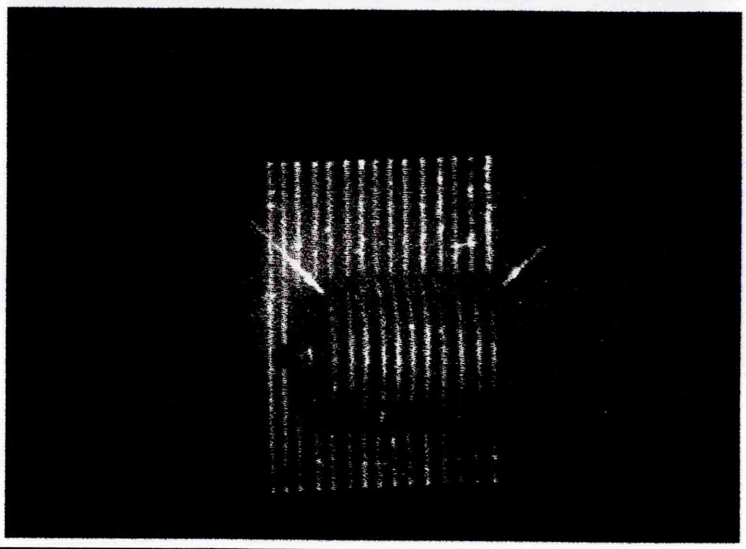


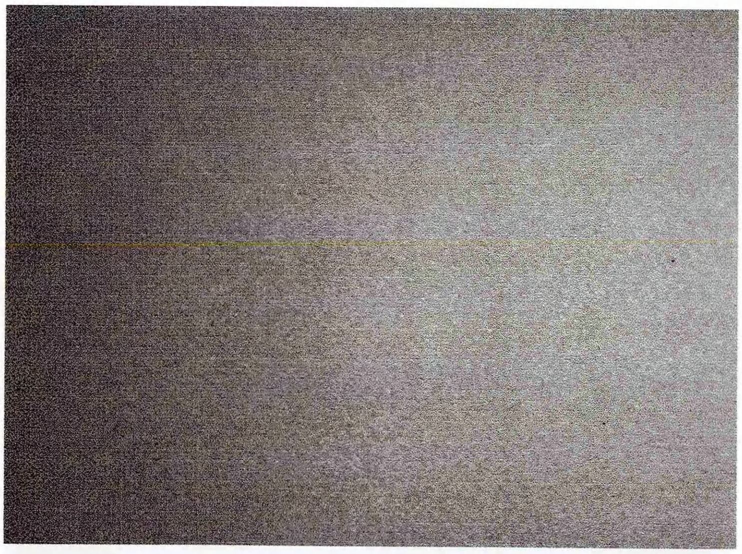
FIGURE 10.20: Barrel target images at 3.5m range with 60g bentonite addition

Lamp Image

Range 3.5m

Bentonite measure = 80g

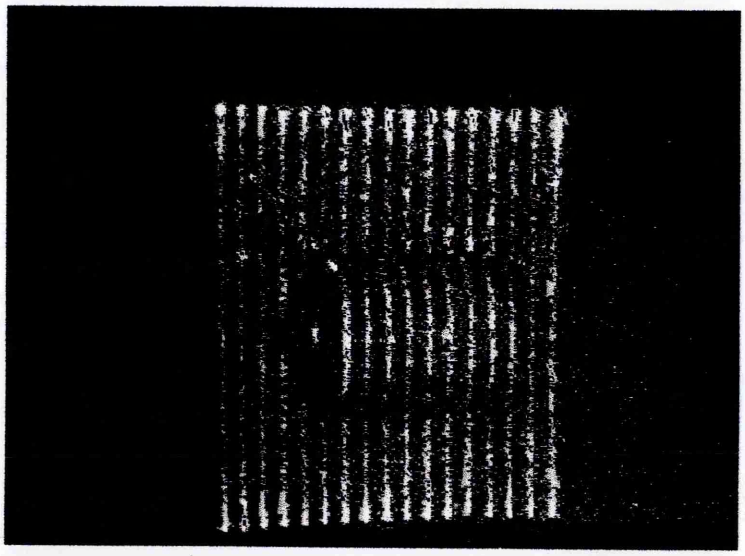
Average NTU reading = 0.579



Laser Stripe 1a.vi

2 stripes p/s

Threshold range = 80 - 255



Minimal gamma 1.vi

3-4 stripes p/s

Gamma setting = 8

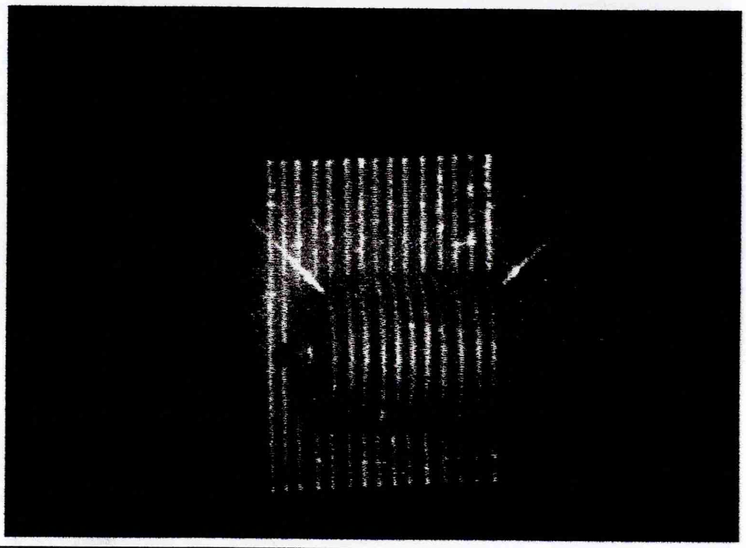


FIGURE 10.21: Barrel target images at 3.5m range with 80g bentonite addition

The first aspect of this test that should be noticed is that recognition of the barrel through the use of the incandescent lamp is effectively lost between 40g and 60g bentonite addition (average NTU readings of 0.42-0.479). Therefore immediately setting a comparison between its use and the use of the laser imaging system, over this range. The images of the target barrel displayed show the altering imaging abilities of the two algorithms used

The consistent features of the laser stripe images are firstly the alterations in geometry between the stripe on the wall and the stripe projected over the barrel. In creasing separation between camera and laser source would define this characteristic further but is limited in these tests by the size of the viewing window. The geometry of the target is further defined by the width of the stripe as it falls upon the barrel, being at its widest on the aspect directed towards the imaging system. As the aspect changes so does the predominant direction of reflection thus reducing the intensity of pixel information obtained from these regions.

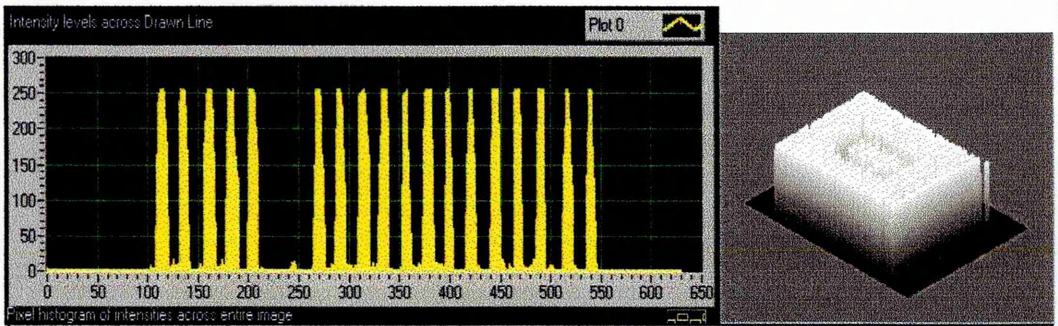
The integrity of the stripe can be seen to fall as the turbidity increases. No results were obtained from the addition of 100g of bentonite as the stripe is longer definable on the wall of the tank. Thus giving a 4m range limitation of between 80g and 100g bentonite addition

Algorithm 'Laser stripe 1a.vi' offers less stripe grabs across the barrel as processing is slower, achieving approximately 2 grabs per second. This can be compared to the 'grabbing' of approximately 3-4 grabs per second through the gamma correction algorithm. Due to the nature of the processing techniques the stripes achieved through gamma correction offer smoother edges to the stripe extracts particularly at higher turbidity levels. This may be the result of the addition of temporal differencing reducing areas of the stripe to an intensity value that falls outside of the threshold range. The gamma correction images do appear to be dimmer but closer investigation shows that values of 255 are still present however the stripe region is thinner than those seen through the alternative method.

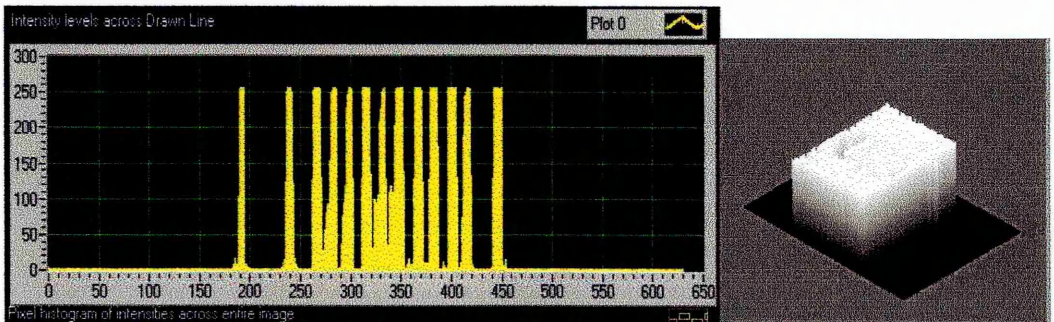
10.5.1 CONTRAST ANALYSIS

The effective addition of the extracted stripes requires all but the immediate stripe region itself to be efficiently reduced to an intensity value of 0. By the removal of scattering noise from an image, contrast is increased improving stripe definition, but the accumulative effect of adding a series of stripes that have not effectively been isolated will result in a build up of noise on the final image. Therefore it is possible asses the success of an algorithm in terms of contrast levels across a cumulative image.

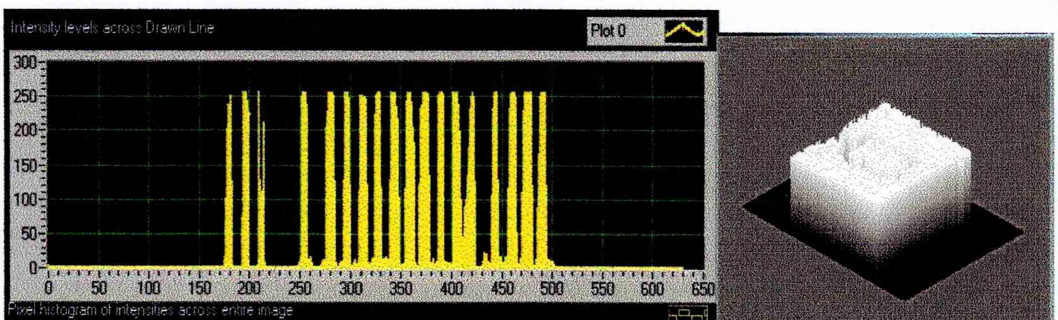
Analysis of the images displayed in figures 10.17 to 10.21 was conducted by measuring the intensity levels across the image of the barrel. These are presented in figures 10.22 and 10.23 alongside a three dimensional representation of the whole image.



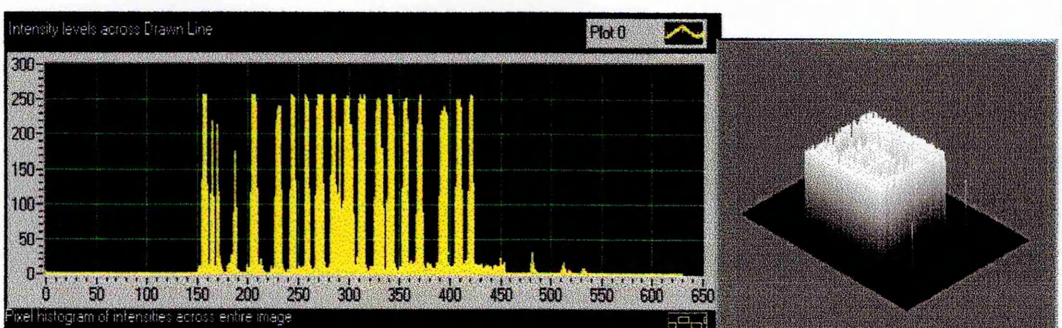
3.5m Clear Water



3.5m 20g Bentonite addition



3.5m 40g Bentonite Addition



3.5m 60g Bentonite Addition

Figure 10.22: 'Laser stripe 1a.vi'. The affect of increasing turbidity on contrast

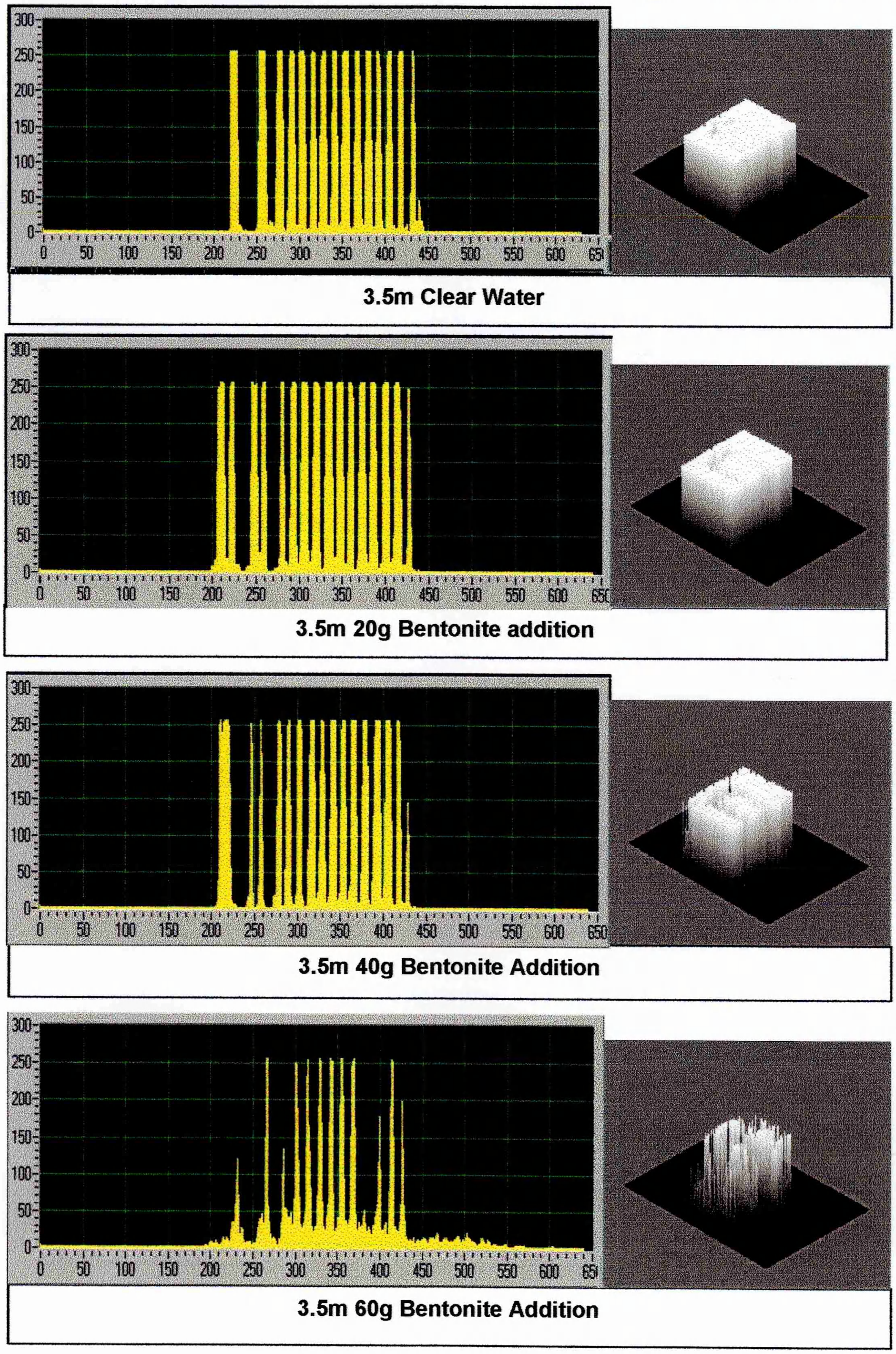


Figure 10.23: 'Minimal gamma 1.vi'. The affect of increasing turbidity on contrast

The results of the contrast analysis presented in figures 10.22 and 10.23, display both algorithms aptitude for stripe isolation. Low levels of undesirable visual information were being carried through to the final image particularly through the Gamma correction technique. This though was not significant until higher turbidity levels were reached around 60g. Near field scattering causing brighter backscatter within the image was not being removed, rather its intensity was being enhanced. The lower level of unwanted data on the final 'Laser stripe 1a.vi' is almost certainly due to the application of the temporal differencing technique.

There was a significant reduction of stripe information being extracted through the gamma correction. Suggesting that there may be an effective limit to the use of this method. There will be a point reached where the effect of raising the Gamma coefficient further will purely result in the intensifying of the visible information whilst not rejecting any unwanted data. In the presence of lower turbidity levels the contrast alterations were noticeably sharper through gamma correction which was expected due to the nature of the operation. The overall effect of applying both techniques though is a significant reduction in backscattering reaching the final target image

10.5.2 ACHIEVABLE IMAGING

The performance of the algorithms show effective object recognition of the barrel at 3.5m with 80g of bentonite added to the tank. However it was discussed earlier that recognition is subjective. Definition of the target may be easier without the stripe shown on the back wall as this distracts the eye from the true subject of the investigation. It has been shown that the importance of intensity variations within a stripe image is limited through both processes particularly as turbidity rises. The details of an image surface which can be shown through variations in the intensity of reflections are largely discredited through scattering and the nature of the processing techniques. Therefore more emphasis should be applied to the geometry of the stripe itself.

Increased turbidity tests indicate that the system can be challenged further through the use of both algorithms. The important factor though is the flexibility of the control. Certain techniques can be offered to the operator to further enhance images such as contrast and brightness controls. These were discounted earlier as direct processing techniques as their use in defining the stripe amongst extensive scattering events would be limited. However once the stripe region is clearly defined through the isolation and extraction processes these controls can become an option.

Figure 10.24 is an image of the orange buoy and horizontal, black and white striped targets over a range of 3m. !20g of bentonite was added to the tank equating to an average NTU reading of 0.822. At this level imaging of the barrel with the arc lamp was not achievable even at 2m. With the addition of a contrast and brightness control to the algorithm, post processing, the extracted stripe can be further enhanced.

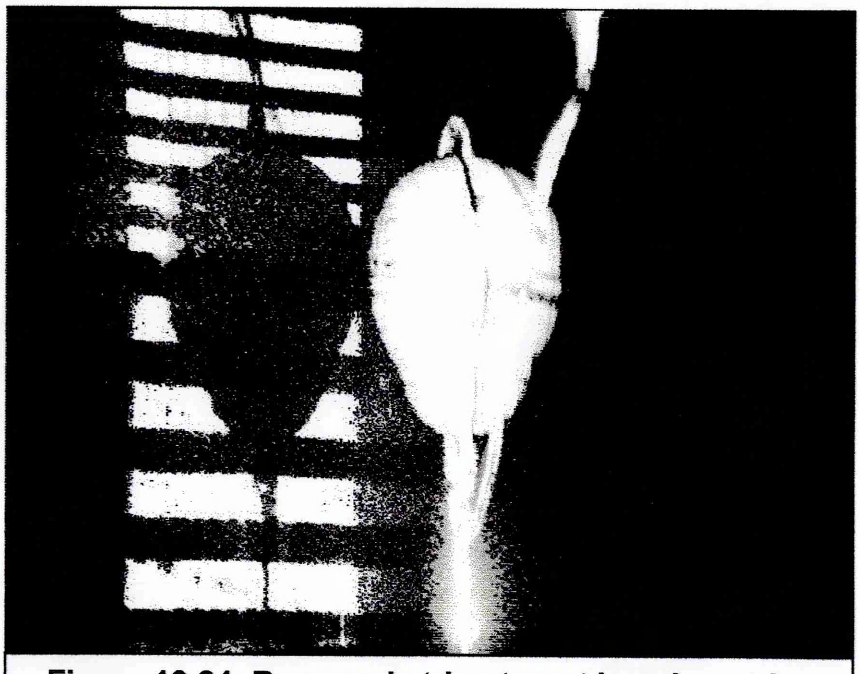


Figure 10.24: Buoy and stripe target imaging at 3m range (120g Bentonite)'Laser Stripe 1a.vi'

This image is achieved through the 'Laser stripe 1a.vi' with a threshold range of 68 to 254, with the addition of brightness and contrast controls. It should be noted that multiple scans were used to create the image. The effect of which can be seen through the build up of scattering events around target regions. As can be expected this scattering is greater in close proximity to lighter regions of the target.

This can be compared to the image shown in figure 10.25, which was processed through the gamma correction technique, with the addition of contrast and brightness controls. The gamma coefficient is set to a maximum Once again this image has been compiled over several scans

Figure 10.25: Buoy and stripe target imaging at 3m range (120g Bentonite) 'Minimal gamma 1.vi'

The scattering displayed in the previous image is not seen in here, indicating an improved ability to remove individual pixel values. Both images though show relatively high definition of target characteristics such as the black and white stripe regions and the rope which secured the buoy. This detail however is very much within the description of 'dark against light' but is significantly better in the gamma correction procedure. To test the ability further, writing was place on the buoy and imaged under the same conditions. Figures 10.26 and 10.27 show the images achieved over 1 scan of the target in the left hand side and on the right hand side the images achieved over several scans are shown.

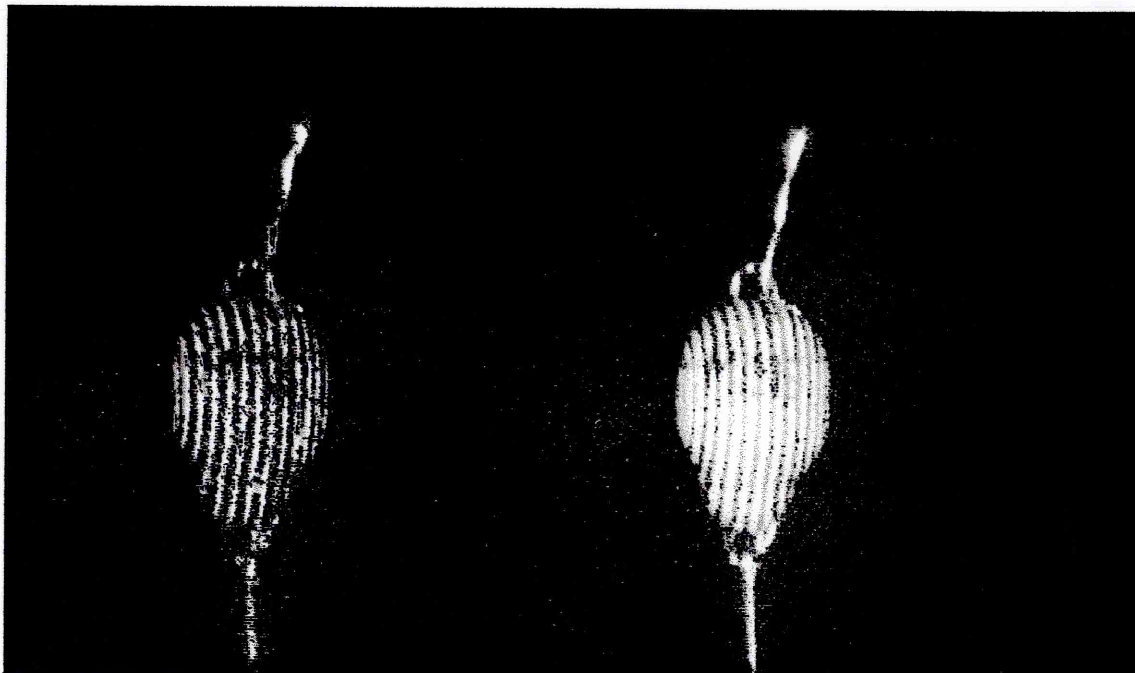


Figure 10.26: Imaging target Buoy at a 3m range (120g bentonite) 'Laser stripe 1a.vi' with contrast and brightness control

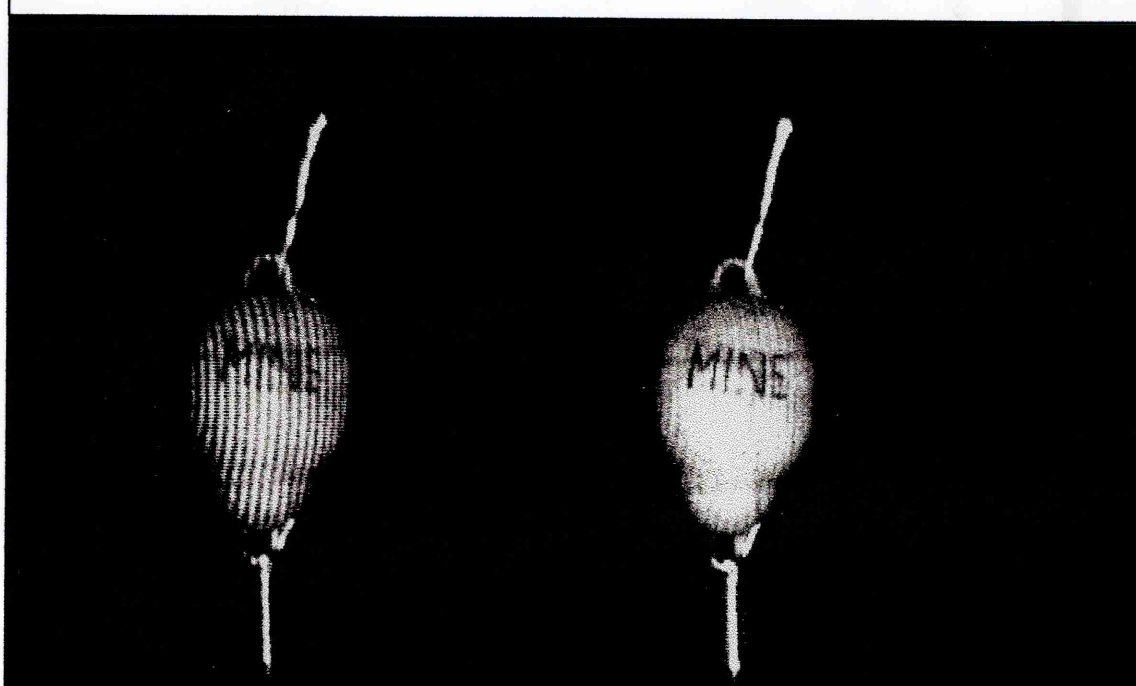


Figure 10.27: Imaging target Buoy at a 3m range (120g bentonite) 'Laser stripe 1a.vi' with contrast and brightness control

Through these images the importance of the smoother, thinner stripe produced by the gamma correction technique can be clearly seen. In addition to appearing more pleasing to the eye, the definition of larger intensity alterations is more noticeable. The effect of a broken stripe edge obtained through 'laser stripe 1a.vi', is to reduce this definition and thus produce a less recognisable image. Whilst this situation is improved over several scans, the writing on the target appears blurred and unclear. The fact that several scans have been used in the compilation of the second image indicates the success of the addition process, as a level of pixel intensity variation is clearly seen, particularly in the gamma correction image

These results indicate a greater potential for the use of the gamma correction technique within the system. For optimum effect though the application of further enhancement techniques should be made available to the operator. Visual inspection and recognition of target object can be further enhanced through the addition of analysis aids such as three dimensional interpretation and zoom options.

11 'Waterfalling' Technique

The system as it lay was developed primarily for forward scanning of target objects positioned in front of the host vehicle in this case an AUV/ROV. Following discussions with the DERA, further use of the system as sea bottom mine scanning tool was proposed.

11.1 SYSTEM ARRANGEMENT

For this purpose the primary stripe scanner would be faced downwards presenting a stripe on the horizontal plane below the vehicle. The second scanner would be redundant in this method instead using the forward motion of the host vehicle to provide progressive scanning. The camera would be slung in front of the laser below vehicle and directed towards the seabed so the laser stripe could be positioned in the centre of the field of view of the camera. This is illustrated in figure 11.1

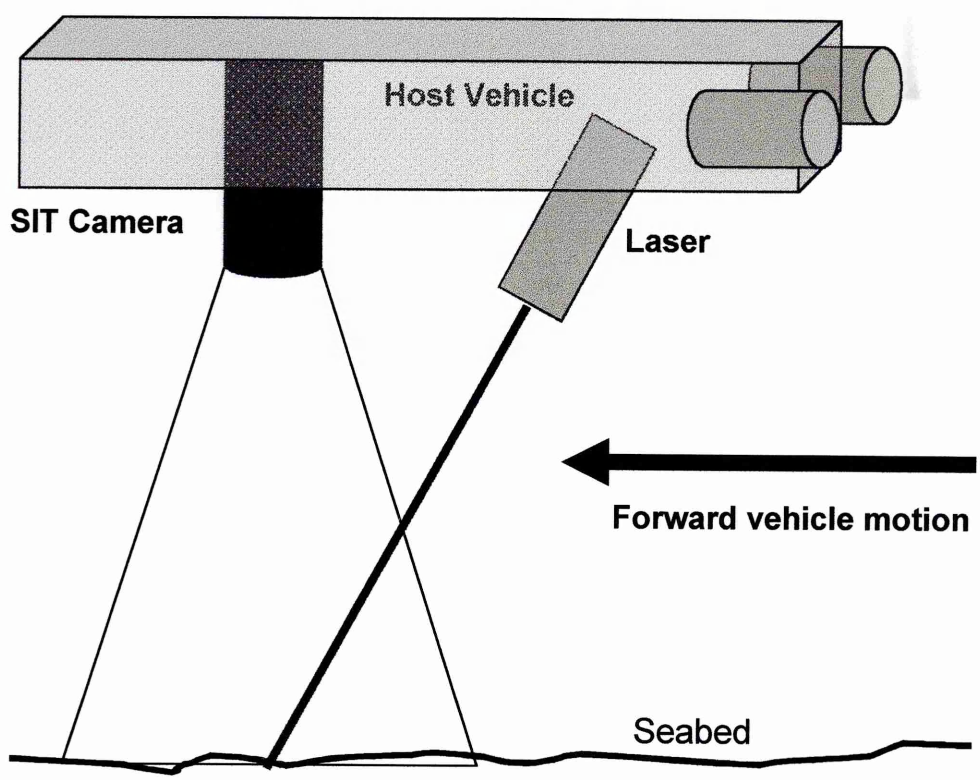


Figure 11.1: Proposed seabed mine scanning system

11.2 'WATERFALLING' PRINCIPLES

The development of this system application required an extension of the successful techniques applied to the forward scanning system. Instead of scanning the field of view, the process could be considered as one continual scan in a single direction. A viewing window for the live image allowed the laser to be calibrated to the centre of the field of view of the camera. As the vehicle moves progressively forward individual stripe grabs are captured and transferred to the top of a cumulation image pushing the previously grabbed stripe down by a preset level. The affect is a series of stripe extractions falling down the cumulative image, hence the name 'Waterfalling' technique. Figure 11.2 illustrates the system process.

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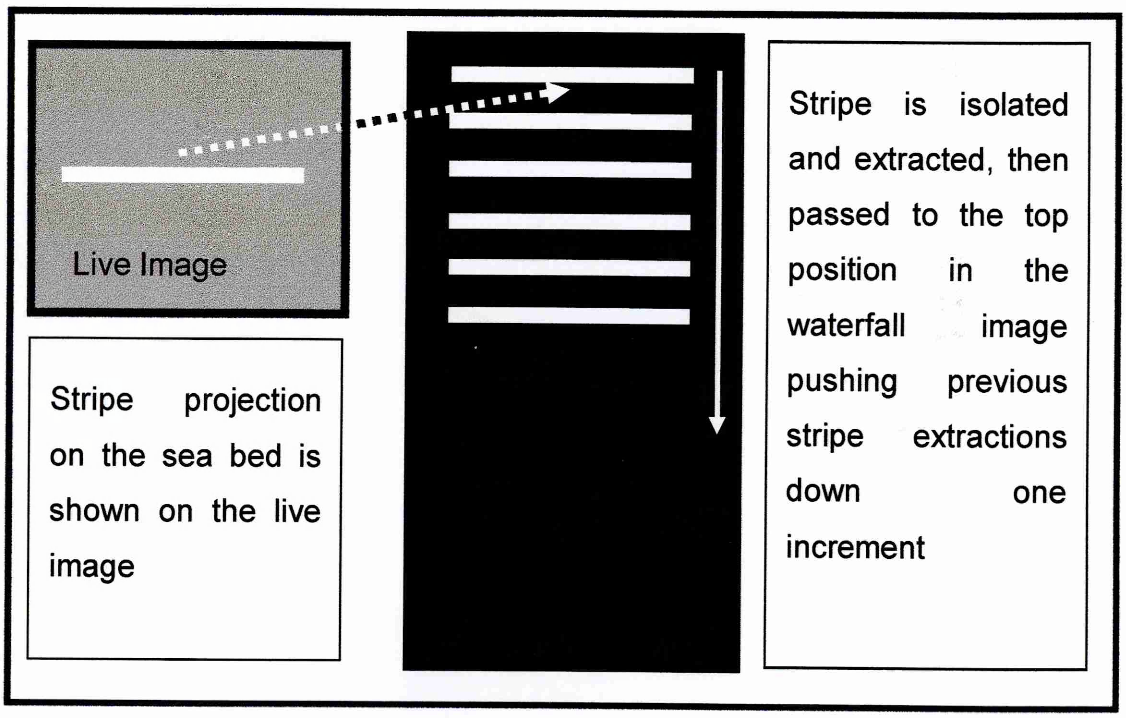


Figure 11.2: Illustration of the waterfall process

An interpretation of the seabed can be built up through the visual information available to the system from the laser stripe. This information falls within recognition of an object in its path in this case the seabed, definition of the geometry of the area of the object that that laser stripe grab is taken from and definition of the reflective properties of the object in the area that the laser stripe falls upon, defined in a greyscale intensity value between 0 and 255.

11.3 'WATERFALLING' ALGORITHM DEVELOMENT

The development of the technique required the same sub-processes used within the forward scanning laser stripe techniques. Individual stripes were grabbed, isolated, extracted and added to the cumulative image. In this technique though, the stripe image in theory will not move across the field of view of the camera, as there is no scanning of the stripe. Therefore the processing must mimic the movement of the stripe as the vehicle progresses. This must be executed through the development of a new addition process.

The isolation of the stripe region would first have to be tackled. This was done through the development of one basic process conducted in three different ways. The previous chapter described the development a novel isolation and extraction process that was capable of closely contouring the defined region to ensure an extraction of only the desired visual information. An irregular region of interest could be defined around the isolated visual and extracted within the boundaries of the ROI. Whilst this extraction process left gaps in the cumulative image, these could be progressively filled as the target was continuously re-scanned. In the case of 'Waterfalling' though the seabed can only be scanned once. It is therefore important to gain the maximum information obtainable in one scan.

Technique 1:

Due to forward scattering events a low level of illumination can obtained around the stripe region dependent upon the level of turbidity. This visual information could be gathered and used to fill the gaps created between stripe grabs. Instead of constructing an irregular region of interest around stripe a rectangular region of interest can be defined by the operator and set around the stripe region. This ROI isolated region can then be passed through the same extraction process to transfer the visual information from within its boundaries to the cumulative window.

The ROI can be positioned around the stripe, by the operator altering the ***x*** and ***y*** coordinates of its centre of gravity. The ROI can also be changed in size along its ***y*** axis to increase or decrease the amount of non stripe visual information to be carried through to the 'Waterfalling' window. These level of operator control over the Region of interest is illustrated in figure 11.3

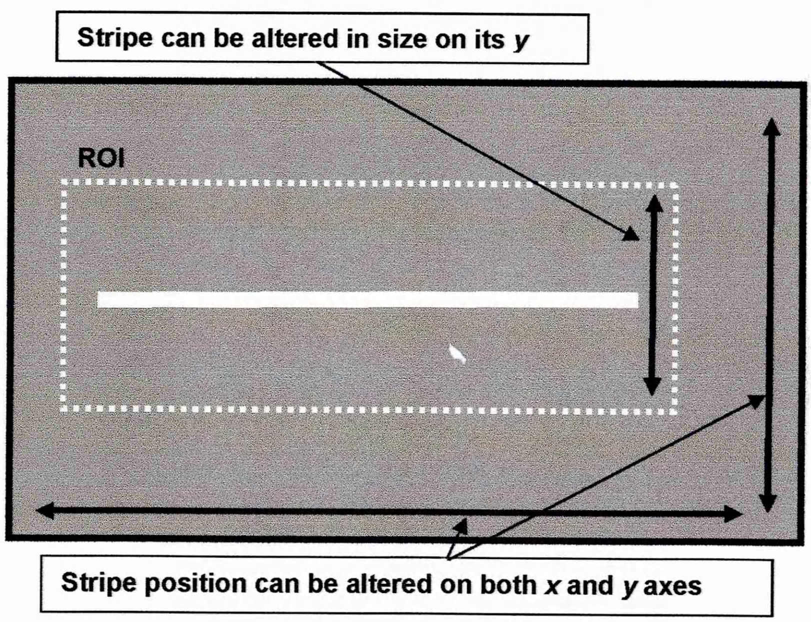


Figure 11.3: Operator control over ROI

The stripe will in effect alter its position within the field of view of the camera as the range to the seabed alters; consequently the operator will be required to constantly update the position of the ROI. The advantage of the technique though is its flexibility. The operator has near complete control over the level and position of the visual information that is extracted. This vi can be seen in Appendix D named 'Waterfall SET ROI.vi'.

Technique 2

The second variation on the isolation and extraction process introduced a level of automation to the region of interest. This application applied the threshold processing tool to set the centre of gravity of a rectangular ROI around the centre of gravity of the stripe. The dimensions of this ROI can then be set by the operator altering the threshold range.

This technique ensured the ROI was always positioned around the centre of gravity of the stripe as it is imaged in the live window. The operator then has near complete control of the visual information to be extracted within the boundaries of a rectangular region and does not have to continually alter the position of the ROI to extract the desired visual information. The difficulty is that control over the ROI through the threshold process is less definable than the previous method and if turbidity is high the required information is not as easily recognised by the operator. This vi is shown in Appendix D named 'Waterfall RECT ROI.vi'.

Technique 3

The final technique applies an irregular region of interest to the stripe. The isolated region is completely controllable by the operator through the threshold range, and extracts are of irregular geometry. This process allows a clearer definition of the geometry of the stripe giving a more three dimensional aspect to the waterfall window. Full automation of the positioning of the centre of gravity of the ROI leaves the operator free to concentrate on the visual information being extracted. The irregular ROI perfectly defines the region of the image isolated through the threshold range. Forward scattering illumination though will tend to fall within lower threshold ranges while the stripe region will be in the higher range. To extract both a wide threshold range must be set resulting in a large level of non useful visual information being carried through to the Waterfalling window. Once again the setting of the ROI dimensions through a threshold range is less definable to the operator and experience of process would be required for its effective use. Less importantly the irregular extractions do not appear as orderly in the waterfall window as a rectangular extraction. The vi for this technique is shown in Appendix D named 'Waterfall IRR ROI.vi'.

11.4 DEVELOPMENT OF THE ADDITION PROCESS

To mimic the movement of the vehicle an offset must be built into the addition process, placing the new isolated stripe region at the top of the cumulative window and separating this stripe from the previously added stripes by an offset spacing, representing the movement of the stripe across the seabed.

The extracted region must first be placed correctly at the top of the Waterfalling window and shift the previously extracted stripes down, this is conducted in the 'vi' through the IMAQ Shift control, shown in figure 11.4

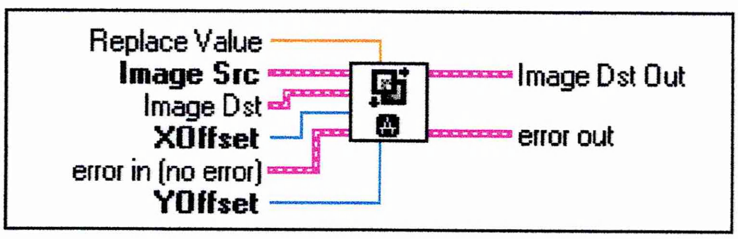


Figure 11.4: IMAQ Shift Control.

The extracted region is passed through the shift control associated with the waterfalling window, and the coordinates of its centre of gravity reposition by the X and Y Offset controls set through the operator interface. The shift control then repositions the previously added visual information down by an increment set by the X offset. This can be set automatically but due to the testing procedure it was advantageous to hold a level of flexibility in the system.

At this point the system still considers the image to only fall within the Region of interest at a set point in an operating window, therefore when it is passed through the subtraction process the change in position if the extracted information does not affect the blacking of the correct area in the waterfalling window. Finally the extract is overlaid on the blacked region by a simple addition.

The ‘waterfalling’ cumulative image holds boundaries that can either be set automatically or to preset limits through the IMAQ GetImageSize and IMAQ SetImageSize functions shown in figure 11.5.

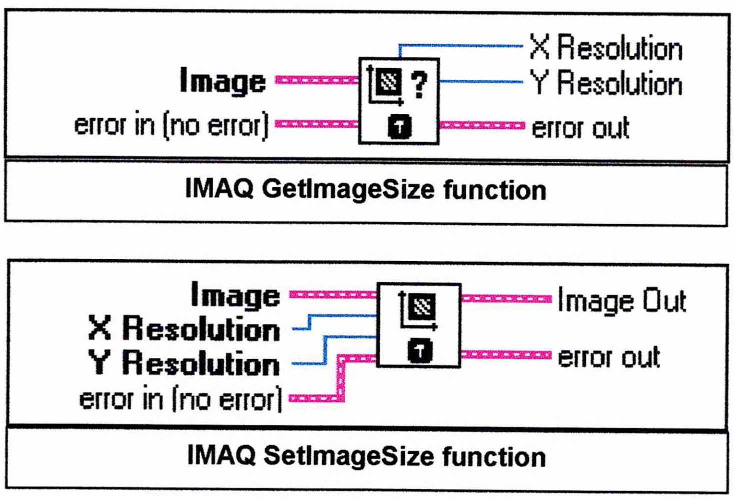


Figure 11.5: Function tools to set image size to automatic or preset values

In the algorithms developed for this system the width or **Y** resolution, of the image is set to the maximum width of the added information and so is flexible enough to allow the scanner control offset to reposition the stripe without affecting the process. The limits of the image in the **X** are either given a high value or allowed to expand in response to the number of added stripes, and thus can expand as long as the process is run. This image is stored and can be both saved separately or printed off continuously.

11.5 TRIALS

Due to the nature of the system full testing of the techniques could not be carried out within the limited space of the Cranfield test tank. So trials were conducted a DERA Haslar in Gosport, Hampshire, in their indoor manoeuvring tank. The facility offers a clean water tank measuring 61m × 122m × 5.5m deep. Figure 11.6 shows the tank with manoeuvring platform.

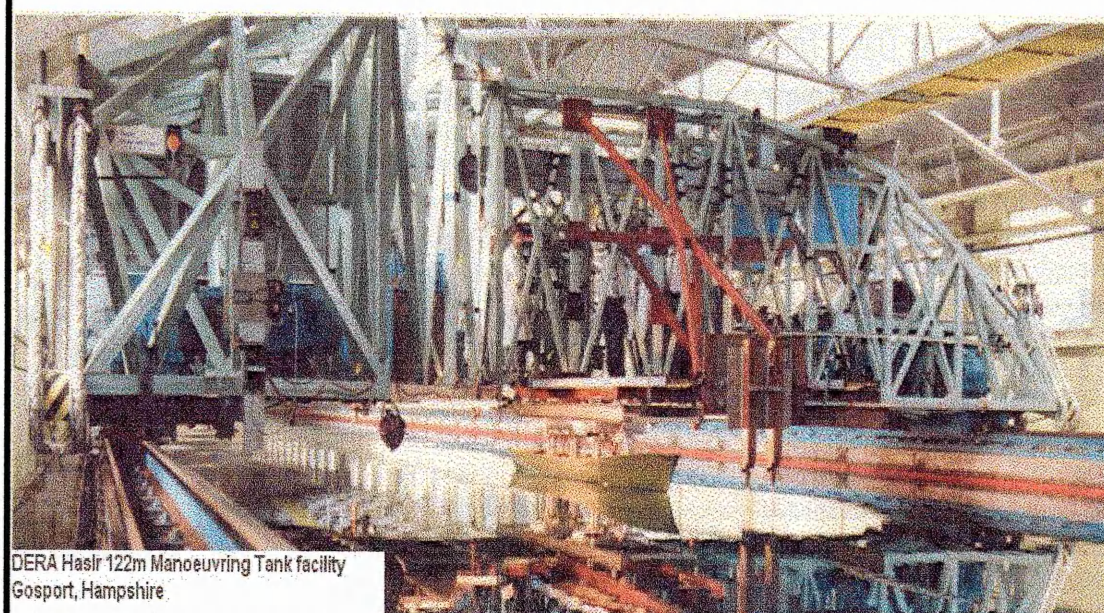


Figure 11.6: DERA Haslar Test tank facility

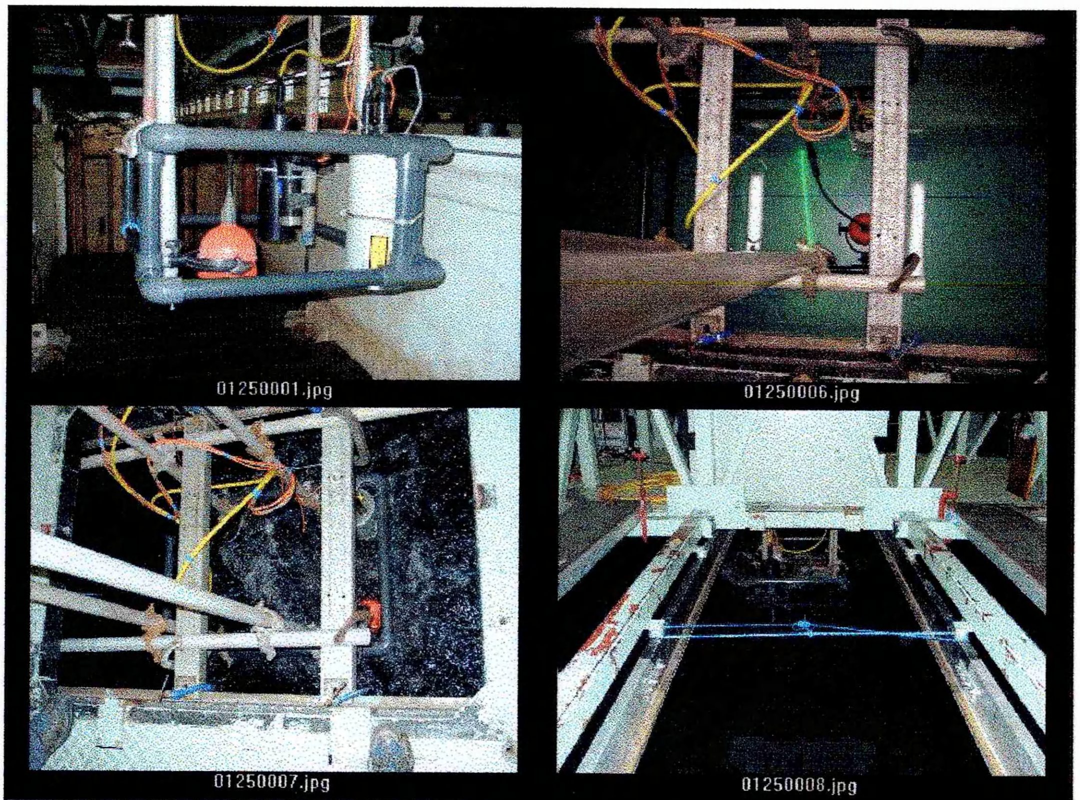


Figure 11.7: Experimental rig operating in the Haslar Manoeuvring Tank

The Test tank includes a platform that can be moved the entire length of the tank at a required speed of up to 30 knots. This allowed the system to be slung below the platform and scanned over the tank floor at various known speeds. Figure 11.7 shows various images of the system operating on the platform. Image A shows the test rig before lowering under the water surface, image B shows the stripe projecting onto the tank floor and images C and D show the rig being manoeuvred through the water

Test Objects were placed on the floor of the tank in the path of the scanning beam. These objects included a seabed mine supplied by DERA an image of which is shown in figure 11.8. The barrel target was also introduced along with various available objects at the time.

Figure 11.8: Seabed Mine in position on the floor of the test tank

It was not possible to apply turbidity to the test tank for the reason of large scale but ambient light was kept to a minimum by conducting the trials at night and extinguishing the internal lights.

11.6 RESULTS

The following figures display waterfall images captured during the trials at speeds ranging from 2 to 5 knots over the various target objects. The range to the tank floor is 5.4m.

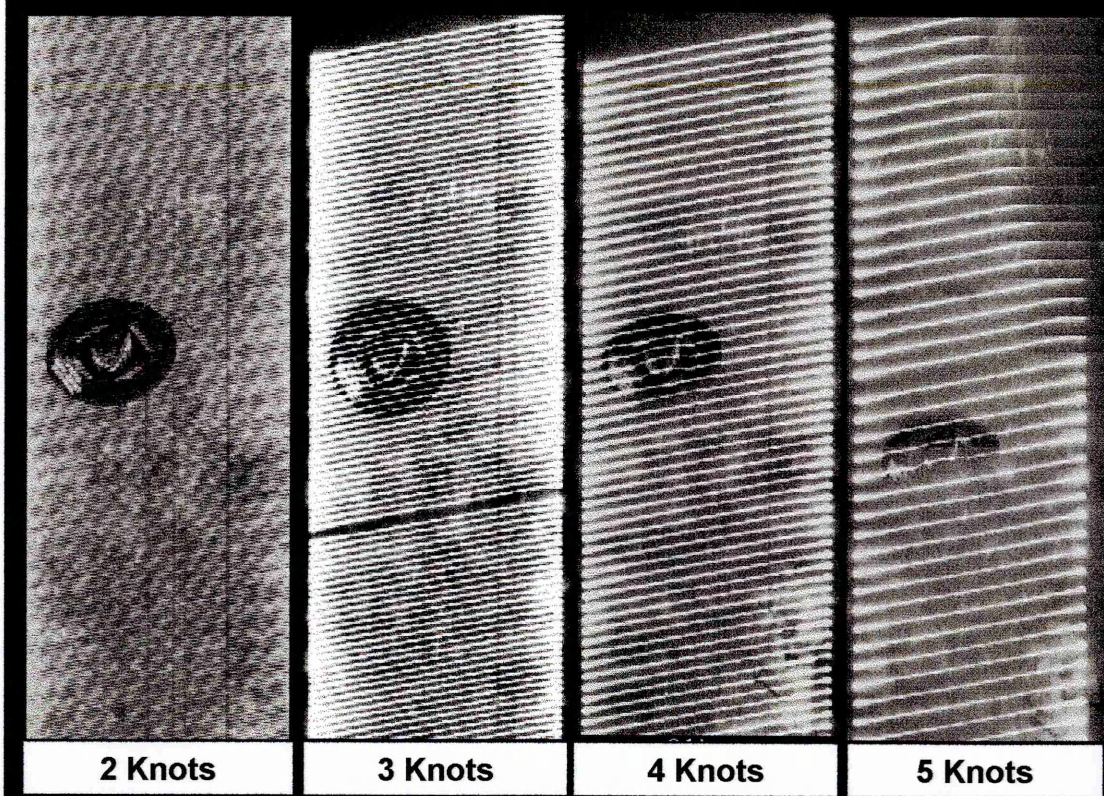


Figure 11.9 Waterfall imaging of seabed mine across various speeds (range 5.4m)

The target mine is imaged here in considerable detail particularly in the 2 and 3 knot ranges. Image definition decreases as scan speed increases to an effective 5 knot limit.

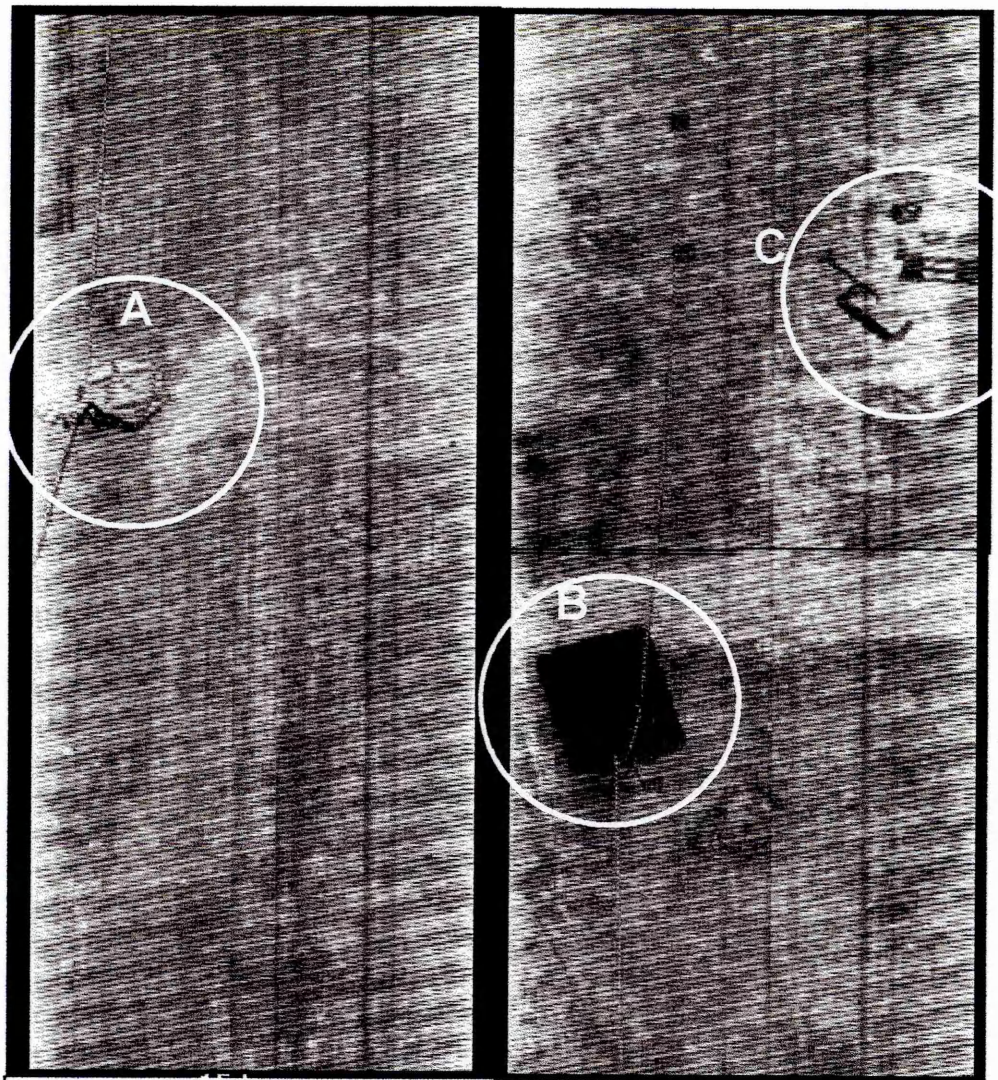


Figure 11.10: Waterfalling scans of various target objects on the tank floor (range 5.4m)

Other objects of varying geometry were imaged and are shown in figure 11.10 these include a sonar invisible buoy in **A**, the barrel target in **B** and a 'G' clamp in **C**.

11.7 DISCUSSION

The captured scan images of the target objects on the tank floor at Haslar clearly showed the potential of the system for purpose of Seabed mine search. This is despite a low level of ambient light being present from street lighting. The images shown, present a high level of target detail over a range of reflective properties.

All three techniques were tested during the trials to assess their performance. The set ROI technique operated correctly producing effective scans of the tank floor. Problems were experienced though in the need to reposition an redefine the ROI as the scan crossed over a target object. The geometry of the stripe alters when objects are encountered requiring a wider field for the ROI to encompass. The result was that the relatively immediate change encountered as the scan moved from flat floor to target object left no time for the manual resetting if the ROI. Thus no clear images were obtained of the targets through this method.

The focus of the trials then moved to the threshold based, semi automatic techniques used in Waterfall RECT ROI.vi and Waterfall IRR ROI. vi. The rectangular ROI technique experienced the same problem as before requiring a quicker method of changing the dimensions of the ROI. The algorithm did follow the position of the stripe effectively though. The automatic setting of the irregular ROI allowed the algorithm to instantaneously react to altering stripe geometry and range, and produced the images shown.

The use of threshold range to set the ROI allowed enough automation to track and extract the stripe correctly, whilst also giving enough flexibility to the system to allow the operator to decide the level of excess material to be extracted with it. Through this, the spaces between the additions to the waterfalling window could be partly filled. The testing of these processes though were in conducted in clear water thus not truly testing their ability.

There is a distinct need for the level of automation shown through the irregular ROI technique, this is due to the realisation that imaging a true seabed will result in constant alterations in stripe geometry and range, and operator control over the ROI position and dimensions are not feasible. The control offered to the operator to allow a level of excess visual information to be extracted was effective in these conditions as a low level of forward scattering events will occur in clear water. To assess its usefulness correctly though, trials in turbid conditions would be required.

12 DISCUSSION

It was important to realise at an early stage of the project that the development of algorithms to work in conjunction with the laser stripe imaging system, would require a targeted approach, matching the processing to the task at hand. The nature of the stripe projections and the need to pass the images individually through a series of processing activities is restrictive and limits the system to close to real time imaging at best.

The optimisation of the processing had to go hand in hand with the development of effective imaging techniques. However, imaging through the system required defining.

The Cranfield Laser Stripe Imaging System was under development for the inclusion in ROV/AUV based surf zone and shallow water mine-hunting arrangement. Initially this inclusion was defined as a search and recognition tool, but this opened the question of priorities of development. It was discussed that the progressive 'grabbing' of individual stripes to allow image processing to be undertaken becomes less effective over increasing range, not only through attenuation of the laser beam but also through the need to reduce cross field scanning speed. It must be recognised that although the laser stripe is continuously scanned across the field of view of the camera, due to the requirements of processing, the imaging of any target object should be considered as a series of individual stripes. The greater the range over which the system is scanning the greater the distance between progressive stripe grabs. To overcome this, the system would have to be optimised for longer range imaging. This though could only occur at the detriment of close range imaging.

It was realised that close range imaging was where the systems strengths lay, and in consideration of the environment in which it would be required to operate, the limitations made on even close to target viewing would be the primary aspect of the development. The inclusion of alternative mine search techniques allowed the research to target the system towards an inspection and recognition tool. This directed the development of the algorithms to primarily deal with the problems created by back scattering media experienced in active coastal regions

12.1 ASSESSMENT OF LASER STRIPE SYSTEM

Before development of the processing algorithms, it was important to first understand the nature of the scanning stripe projections, and to realise the properties that a grabbed stripe would hold in terms of useful visual information. Firstly the laser is a monochromatic light source, illuminating any object that falls within the path of its scanning beam, in the form of a stripe. Imaging of this stripe appears as an elongated region of raised pixel intensities across a greyscale range, which can offer visual information in several ways. These are:

1) The stripe can recognise the presence of an object in its path, through alterations in stripe geometry mapping the surface of the object on which it falls.

2) A stripe can define the shape of the object over the region on which it falls. This definition can be through the geometry of the stripe, or through alterations in the intensity of reflected light as the predominant direction of reflection alters.

3) The intensity of the reflected light can also define the reflective properties of the surface on which it falls.

The task for the processing techniques used within any algorithm is to isolate, extract and enhance this limited visual information to produce the best possible image of the object. It was discussed though that as turbidity increases the value of the observed intensity variations can be limited due to the scattering and repositioning of the reflected light.

These scattering events can occur over the outward path of the laser beam attenuating the intensity and reducing the integrity of the stripe. They can also occur on the return path of reflected light resulting in a proportion of the light returning to the system in a chaotic manner. The overall result on the image is the presence of individual or small groups if pixels appearing on the image with varying intensities. This noise degrades visual information and is the primary limitation to illuminated underwater imaging.

A green laser is utilised by the system to increase light penetration through the scattering medium. However, scattering will attenuate the intensity of the beam and as turbidity rises increased scattering will eventually limit the range of the system resulting in contrast limitation. With reference to the issue of beam divergence discussed earlier, inspection of stripe image over an increasing level of turbidity show that it is more an issue of beam convergence, as the scattering of the beam intensifies. This is a confirmation of the statement made by Abercrombie [12.1]

12.2 IMAGE PROCESSING

For the development of the algorithm three separate processing stages had to be considered. Firstly stripe identification and isolation. The algorithm must be capable of identifying the region of the stripe by means of its characteristics and be able to isolate this region from the rest of the image. Secondly this region had to be extracted on its own and passed to the cumulative Image, where the final stage of the process; the effective addition of each isolated region, would occur.

12.2.1 VISION BLOX ALGORITHM DEVELOPMENT

The initial selection of the Vision Blox image processing system was primarily due to the system already being integrated with the laser operation on commencement of the project. Programming of the algorithms was carried out in visual basic instructing the operation of certain integral tools, which were previously identified for possible use in the processing of the images.

12.2.1.1 Stripe Identification and isolation

The development of the identification and isolation processes was based on a 'temporal differencing' technique identified by Tetlow [(12.2)]. By subtracting progressive grabbed images from the subsequent image, the level of noise could be degraded in intensity or removed completely from the image. The process would also result in the removal of 'bright spots' caused by near field scattering which can have an unproportional effect on the received image. This technique was shown to be relatively sound in theory and operation, significantly reducing backscattering noise particularly from within the path of the scanning beam.

Within the Vision Blox image processing system all algorithms utilised this technique to enhance the definition of the stripe region, prior to stripe identification. Although this method was shown to be far from ideal in terms of the optimisation of the image processing time, preparation of the image through this method was required to support the use of the stripe identification tools.

Three methods were included in the Vision Blox algorithms for the identification of the stripe region, these were;

- The Edge Tool, which identified the edges of the stripe by means of the characteristics of contrast, polarity and position. The isolation of the of the stripe region would then be carried out through the use of a region of interest set by the defined position of the edge tool, The requirement of the tool to be trained to identify the ever altering characteristics of the stripe within a limited region of interest, left the algorithm inconsistent and unstable. Further the identification of the stripe was by means of one edge resulted in an offset region of interest which could only be adjusted by means of guess work. The tool could not be made sufficiently flexible to position the region of interest consistently around the correct region of the stripe, without the addition of extensive further processing.

- The Caliper Tool enabled the identification of two edges by means of opposing polarity. This technique although defining two edges and so offered a higher degree of stripe data, was still restricted by the need to train the tool within a reduced region of interest. The restriction of using this reduced ROI was that it offered limited stripe data as much of the stripe falls outside of its boundaries, lessoning the ability of the tool to closely map the stripe region with the floating ROI. Increasing the size of the region of interest would slow the algorithm. The addition of a level of operator control to the dimensions of the floating ROI enabled some flexibility, but was not ideal as the operator would be required to continually update to react to altering stripe characteristics. Once again the tool could not be relied upon to efficiently track the projection stripe and frequently resulted in disablement of the algorithm..

- The Blob Tool proved to be considerably more promising, as it identified the region of the stripe by means of threshold intensity isolation. There was no need to restrict the search area to a reduced region of interest and the stability of the algorithm was significantly improved. The tool offered increased stripe data in terms of **x** and **y** axial dimensions and a centre of gravity which allowed an effective level of automation to the setting of the position and dimensions of the floating ROI. Operator control could be offered through the adjustment of the threshold range. The effective use of the tool though was restricted by the limitations of the image processing system. The projected stripe is not a standard geometric shape even when imaged against the flat wall of the test tank. Vision Blox did not have the capability to set a region of interest to closely contour the edges of an irregular shape, therefore despite the success of the tracking of the stripe and the positioning of the rectangular ROI around the stripe, excess visual information was still seen to be extracted with detrimental effects of the cumulative image. A technique of stripe trimming was applied which offered an partial answer to the problem but its inflexibility lay in the geometry of the ROI limiting its use to strait stripe projections on the test tank wall.

12.2.1.2 Stripe Extraction

The success of the extraction process was highly dependent upon the efficient positioning of the floating region of interest. This ROI firstly defined the area to be extracted and secondly provided the coordinates for the positioning of the extracted region within the cumulative image. With respect to this the technique performed precisely as designed with a minimum of processing required.

12.2.1.3 The Addition Process

The addition process required the implementation of an operation that could not only add the visual information to the cumulative image, but also reject all previously added information that lay in the area of the new extraction. Without this, an accumulation of pixel intensities would occur, resulting in an effective 'white out' of the image over several scans.

12.2.1.4 Assessment of Vision Blox image processing

The use of the Vision Blox image processing system proved restrictive from an early stage. Identification of the stripe region was erratic and unstable, particularly in the edge and caliper tool techniques, causing the algorithm to crash if identification of the designated feature was not forth coming. The use of the blob tool to identify regions within an operator set threshold range however enabled an effective and relatively stable algorithm to be constructed. The extraction and addition processes showed no identifiable problems in their operation but were hampered by the restricted geometry of the extracted regions.

Vision Blox was unable to allow the laser imaging system to perform to its potential, primarily due to the inability to extract an irregular shaped region. It was discussed that the only solution held within the image processing system would be the use of multiple floating regions of interest operating on their own plane. In this way each ROI could isolate and allow the extraction of individual sections of the stripe. The level of processing required to achieve this however, renders this option out of the question as optimisation of the processing time is paramount.

12.2.2 LABVIEW ALGORITHM DEVELOPMENT

The development of image processing algorithms within LabVIEW offered the opportunity to compare the integration of different image processing systems within the laser stripe operation. It also allowed a further exploration of different image processing techniques unavailable through Vision Blox. Unfortunately LabVIEW requires knowledge of an entirely unique programming technique. Offering a wide range of operating tools and processes, the system is programmed by means of 'virtual wiring'. Each operating tool has a range of input and output options that can be configured to alter its operation to achieve the desired results. Whilst sub programming can be carried out in C++, the wide options available through the system provided several identifiable techniques that where utilised.

12.2.2.1 Stripe identification, isolation and extraction

The identification of the stripe region was conducted firstly through the construction of the temporal differencing technique in tandem with a threshold control. This threshold control worked on the same principles as the 'Blob' tool within Vision Blox without placing the attractive colours over the isolated region. Instead it effectively masks the region from which a freehand region of interest can be automatically drawn. The availability of this option was of key importance, as now only the required visual region could be isolated.

However, LabVIEW does not directly allow the extraction of the information held within this freehand Region of interest. The development of a process that would effectively allow this was an important step, enabling the accumulation of stripe extracts with a minimum of excess information and combining both the isolation and extraction processes in one. The technique though was not 100% perfect. If individual scattering events fell within the threshold range this would be carried through within its own region of interest.

The inclusion of temporal differencing was once again made to prepare the stripe image prior to identification of the stripe region. The construction of this technique within LabVIEW was difficult and time consuming, as there seemed no obvious way to hold the image whilst a second image was grabbed. This was due more to ignorance of the options than any failing on behalf of the processing system. Despite this a solution eventually presented itself in the form of the IMAQ Copy function. The resultant technique though proved slow in processing, not only due the number of steps required to perform the operation but also due to the requirement to hold and process two images at any one time.

The combination though of these techniques provided an algorithm that was comparable in speed to that of the 'Blob' tool in Vision Blox. Total stripe processing time for the algorithm was in the region of 0.5 seconds, and an improvement was desirable.

A second route was sought that could firstly efficiently isolate the stripe region without the inclusion of a preparation technique and secondly allow the visual information beyond the isolated region to be nullified. An answer was found in the use of the gamma correction function which performed all the desired operations in a single stage. It was also no longer necessary to hold and process more than one image at a time. Therefore its addition significantly sped up the total algorithm processing time to approximately 0.3 seconds. The disadvantages of this function are that gamma correction operates by altering the pixel intensities across an image. The extent of this alteration is defined by the gamma coefficient set by the operator.

12.2.2.2 The Addition Process

Due to the entirely different nature of the extraction processes two versions of the addition technique were constructed. Both methods are described earlier but the important point to make is that without the need to ensure the integrity of the region of interest the gamma correction extraction can be immediately subtracted from the cumulative image as all other values outside of the stripe equal 0.

The use of the Gamma correction function resulted in a considerable simplification of the entire process. Leaving the effective identification, isolation, extraction and addition processes in two basic techniques. Thus, making a large step towards optimisation of the entire algorithm.

12.2.2.3 Assessment of LabVIEW image processing

Once the initial confusion created by the unique programming techniques used within LabVIEW were dispelled, clear advantages over the Vision Blox system could be seen. Instant tools were available providing a high level of flexibility with no requirement for further programming in the traditional way. Connecting individual processing steps is carried out through the drawing of 'virtual wires' between the output of one function and the input of another.

The clear advantages of LabVIEW to the laser stripe system were the freehand region of interest and the gamma correction options. They made available the development of two entirely different techniques for processing the stripe images. Options that were not available within Vision Blox.

12.3 ASSESSMENT OF OVERALL ALGORITHM PERFORMANCE

12.3.1 Analysis Programme

The analysis algorithm was constructed to provide specific data on pixel intensity values across an entire image. In using this algorithm an attempt was made to explore the relationship between these values and implementation of different processing techniques.

12.3.2 Image analysis

The bases of any algorithm used to process and compile stripe images is the efficient isolation of the stripe region from scattering light that appears in regions outside of the stripe itself. Analysis of the algorithms was directed primarily at this feature. Testing of the effectiveness of threshold isolation and gamma correction procedures both showed a high degree of lower intensity pixel removal capability. It was mentioned though that the presence of a low intensity pixel across an image is by no means an indication that it is not useful stripe information.

Variations in pixel intensities can be primarily put down to two factors: 1) Differences in the angle of reflection, and 2) differences in the reflective properties of the surface of an object. In the case of visualising a target object such as the barrel target, factor 1 will offer information on the geometry of the target such as the curvature. Whilst factor 2 will offer surface detail such as writing in different colour paint. In a highly turbid medium though there are further aspects to be considered. As light is scattered Intensity will be lost producing a pixel intensity variance of no actual use to the image. Scattering also displaces visual information reflected from the target thus also rendering this intensity variance of no use to the image. These scattering events can occur both outside and inside the region of the stripe as such their presence may be predictable but not definable.

It is the nature of both these processing techniques that there is no actual discrimination between the stripe region and the rest of the image. Both processes operate on the separation of pixels by their intensity value. Due to the somewhat random nature of a proportion of lower intensity pixels, parts of the stripe region may be discounted through either processing technique

The application of the temporal differencing technique can actually worsen this situation. Scattering around a grabbed stripe can appear over the same region as the next grab will be taken. By subtraction of the stripes high intensity pixels representing useful visual information from the stripe region can be reduced in value. When passing this through a narrow threshold range these lower intensity pixels may be discarded. In extreme cases this can degrade the integrity of the stripe significantly.

IT was possible to recognise the consequence of applying the temporal differencing technique through inspection of the data achieved through the analysis algorithm. In table 10.2 the processed stripes showed a significant reduction in the proportion of the image with 255 values against unprocessed stripes. For example it was seen that in clear water 2.61% of the analysed image fell into the 255 value, before being passed through temporal differencing. After the application of this method the percentage fell to 1.32%. Nearly half the 255 values had been reduced. This reduction was greatly increased as turbidity was raised. With the addition of 60g of bentonite the percentage fell from 0.66% to 0.04% of the analysed image.

It can be seen then that the presence of pixel intensity variance across a stripe region should not be treated with primary importance particularly through the use of 'Laser stripe 1a.vi' which utilised the temporal differencing technique. In higher turbidity then the threshold range should kept high and narrow for the achievement of best results.

The use of gamma correction increases the contrast of an image by raising higher pixel intensities and reducing lower intensities As the gamma coefficient is raised the separation is increased, effectively removing lower intensity pixels altogether and increasing the definition of the stripe region. This technique also places less emphasis on the presence of low intensity pixel values and once again for best results in high turbidity the gamma setting should be kept as high as possible. This is supported by the individual stripe images shown in the results section.

12.3.3 Direct Visual Comparison

To assess the effectiveness of the complete algorithms written within LabVIEW it was important to keep one eye upon the aim of their development. It was not a priority to improve the range over which a laser stripe can be projected through raised turbidity, but to achieve the best possible imaging of objects that the stripe falls upon, within its range. Light from a laser source can penetrate turbidity significantly further than more conventional illumination sources. The difficulty is that illuminating an object with a laser is confined to the discreet region that it falls upon. To compile a total image from discreet regions, requires the laser to scan the entire surface of the object and image processing to compile a cumulative image from the visual information available.

Despite the highly directional nature of a laser significant backscattering still occurs and degrades the image of the stripe. In high levels of turbidity the accumulation of the image from individual stripe grabs can be seriously degraded making object recognition a difficult task. However, as discussed earlier, in a series of images of a laser stripe scanned through high turbidity, there exists a lot of visual information that can be isolated and enhanced to create an interpretation of the object and thus improve recognition.

It was as an inspection and recognition tool that the laser imaging system was to be integrated into surf zone and shallow water mine hunting systems. Thus the important factor was to develop the ability of the image processing system to create a more recognisable image of a target object.

A range of barrel target images where included in the results to allow the reader to directly compare the two processes and further compare these images to the barrel illuminated by the arc lamp under the same conditions The question was, how is a recognition tool best assessed? It was discussed previously that recognition is a subjective issue and the ability of the viewer to recognise an object is very much based upon their experience and knowledge. As it was mentioned if in the process of this project it was stated that a target object was recognisable at a particular range and turbidity level, this statement may not apply to operator attempting to recognise an unknown object under the same conditions, thus rendering the result meaningless.

It was therefore better to identify the target object and present the reader with the results of the processing techniques and allow them to offer their own judgement.

There is much that can be offered through LabVIEW that can further improve the visual inspection and recognition of a target object. This includes the use of zoom functions and immediate data retrieval. The analysis algorithm was also written in a live version allowing real time images to be assessed through pixel intensity values. This aids the operator in the selection of the correct threshold or gamma setting.

The addition of contrast and brightness controls included after the extraction of the stripe region can further enhance the images achieved. Presenting excellent results such as those shown in figures 10.18 and 10.19.

12.4 FURTHER CONSIDERATIONS

There are certain aspects though that should be recognised and were clearly evident during trials carried out inside the harbour at DERA Bincleaves. These algorithms were developed and tested whilst the laser and camera were housed in the viewing window of the test tank, with the target objects positioned stationary within the field of view of the camera. In reality this would not be the case. The housing of the imaging system on a ROV/AUV host, would result in the continual movement of the target across the field of view of the camera as the host vehicle moves under the influence of currents and its own propulsion. Imaging under these conditions requires as close to real time processing as possible. The greater the delay between subsequent grabs, the more likely the image is to appear deformed and so reducing the ability of the operator to recognise the object.

The restriction of the viewing window limits the camera to laser separation, but the stripe imaging could be significantly enhanced through a greater angle of beam projection over the target. Mounted on a host vehicle the system would be restricted by the size of the ROV/AUV.

A highly noticeable feature of stripes passed through temporal differencing is that the method produces different results dependant upon the direction of the scan. Assuming the system is configured with the laser scanning beam entering the field of view of the camera from the left the subtraction of succeeding stripes would result in a higher degradation in stripe intensity when scanning from left to right. Therefore an effective threshold range for one scan may not be as effective over the returning scan, leaving the technique inconsistent in terms of result.

12.5 'WATERFALLING' TECHNIQUE

The development of algorithms for use in the laser scanning system took a slightly different route during the course of the project to enable the sponsors to investigate its use in scanning for seabed mines. Whilst this may seem to be a distraction from the overall aim of the project, much the same principles applied to this method of imaging.

With the projection of the stripe downwards and positioned horizontally across the field of view of the camera, continuous forward scanning could be provided by the movement of the host vehicle over the seabed. Effective, continuous imaging over floor of the manoeuvring tank at DERA Haslar was achieved.

Three image processing techniques were developed with progressive levels of automation included. The images shown in the results were obtained through 'Waterfall IRR ROI.vi'. This was due to the lack of clear results obtained from the other two algorithms. Due to the nature of the system in this configuration it was clear that the freehand region of interest method provided the correct balance between automation and operator adjustment. Testing of this technique is required in turbid or 'real world' conditions to assess its performance correctly.

The inclusion of a low level of excess information from out side the immediate area of the stripe can show imaging detail through forward scattering events but this is only an issue in low levels of turbidity and clear water. Therefore it should not be considered as a realistic technique

The result showed a clear potential for this technique and further development could produce a particularly effective tool for seabed mine scanning. This development though was carried out before the investigation of the gamma correction function, used within the forward scanning system and it is felt that by applying this technique to the Waterfalling algorithm could significantly enhance its performance.

The operation of the laser stripe system in this form offers a possible technique to over come some of the issues raised in its use. Firstly by pointing the laser stripe scan forward in the traditional manor. The stripe can be continuously scanned in one direction through the forward movement of the host vehicle. In this way the irregular results achieved through alternative scanning directions can alleviated. Secondly this would also reduce the detrimental effect of movement across the camera field of view, by using the movement of the host vehicle to provide one axis of the scan.

12.6 CONCLUSIONS

1) Vision Blox Edge and Caliper tools do not offer enough data to enable effective stripe isolation and are restricted by their requirement to be trained to recognise edges through a statistical model.

2) Despite the ability of the Vision Blox 'Blob' tool to track the stripe and position the region of interest effectively around the stripe region. The inability of the image processing system to construct and extract through a freehand region of interest renders the development of algorithms through Vision Blox meaningless.

3) Effective imaging can be achieved through the use of the developed LabVIEW algorithms over ranges greater than that of the traditional illumination source.

4) Significant progress has been made towards full optimisation of the algorithm processing speed. This is particularly true with use of the gamma correction algorithm named 'Minimal gamma 1.vi' processing stripes approximately every 0.3 seconds.

5) Primary visual information is achieved through the geometry of the extracted stripe and its efficient isolation should take prominence over other visual information. Improved recognition of geometric shape could be achieved with an increase in the convergence angle between laser and target.

6) The isolation of the stripe region has been optimised, effectively removing the presence of scattering from isolated and extracted regions.

7) The development of the algorithms has seen a notable improvement in imaging over ranges of 4m or less

8) In raised turbidity levels, less importance should be placed upon the extraction of lower intensity visual information for the achievement of best results. The value of pixel intensity variations is vague particularly in high turbidity conditions

9) Temporal differencing can result in degradation of the stripe if used in tandem with an intensity based isolation technique such as thresholding.

10) The usefulness of the temporal differencing technique within the algorithm is outweighed by the processing time required to undertake its operation.

11) Although Gamma correction results in the alteration of pixel intensity values the loss of any possible visual information through this can be outweighed by the success of its performance in raised turbidity.

12) The development of waterfalling algorithms through LabVIEW showed a clear potential for the system for seabed mine scanning. But further testing in turbid conditions and over a true seabed is required. The correct balance between automation and operator control was found through the use of the 'Waterfall IRR ROI.vi', but further improvement could be made with the application of the Gamma correction function.

REFERENCES

Section 1

1.1 Kirk, J. T. O.,

Estimation of the absorption and the scattering coefficients of natural waters by use of underwater irradiance measurements,
Appl. Opt., 3276- 3278, 1994b

1.2 Jaffe,J.F., Dunn C.

A model-Based Comparison of Underwater Viewing Systems
SPIE. Vol.925, Ocean Optics IX 1988, pp 344-355

Section 2

2.1 Naval research advisory committee executive summary unmanned vehicles in mine counter-measures
http://nrac.onr.navy.mil/webspace/exec_sum/00umv.html

2.2 Takel S., Duke A., Morrison J.,

Very shallow water and surf zone mine counter-measures vehicle concepts,
International UUV Symposium, Newport RI. April 24-28, 2000

2.3 Jaffe J.S., Moore K.D., Zawada D., Ochoa B.L

Underwater optical imaging: new hardware and software

Sea Technology, July 1998 pp 70-74

Section 3

3.1 ROV.org
ROV committee of the Marine Technology Society

3.2 What the Future Holds for ROVs and AUVs
Underwater Magazine, College of Oceaneering
May/June 2000
www.diveweb.com/uw/archives /arch/mayjune00.03.shtml

3.3 **Whitcomb L., Yoerger D., Singh I.,. Howland J.,**

Advances in underwater robot vehicles for deep ocean exploration: navigation, control, and survey operations.
Robotics Research - The Ninth International Symposium Springer-Verlag, London, 2000,

Section 4

4.1 **Tetlow S.**

Use of Laser Light Stripes to Reduce Backscatter in an Underwater Viewing System
PhD Thesis, Cranfield University, 1993

4.2 **Pope, R. M. and E. S. Fry,**

Absorption spectrum (380-700nm) of pure water. II. Integrating cavity measurements
Applied Optics., 36(33), 8710-8723. 1997

4.3 **Davies-Colley, R.J., Vant W.N., Smith D.G.**

Colour and Clarity of Natural Waters: Science and Management of Optical Water Quality
NIWA-Ecosystems, National Institute of Water and Atmosphere, Hamilton, New Zealand. *1993*

4.4 **Gordon A., Boston B.**

Clear Imaging in Muddy Waters, A plain mans guide to alpha
Journal of Offshore Technology
Vol. 1 No 2, Aug 1993 pp34-38

Section 5

5.1 **Undewasserfotografie**

Underwater photography the Beginning

http://www.unterwasserfotografie.de/enfoto.html

5.2 www.vdst-visuelle-medien.de/klb/index.html

5.3 **Hotographytips.com**
"Natural Light and Visibilty"
http://www.photographytips.com/page.cfm/352

5.4 **A flash of light, Part1 Dawn of the Flash bulb**
http://photography.about.com/library/weekly/aa032601a.htm

5.5 **S. Harsdorf, R. Reuter S.Tonebon**

Contrast enhanced optical imaging of submersible targets

5.6 **Briggs R.O., Hatchett G.L.**
Techniques for Improving Underwater Visibility with Video Equipment
Pp1284-1308

5.7 **Tetlow S.,**
Use of Laser Light Stripes to Reduce Backscatter in an Underwater Viewing System
PhD Thesis, Cranfield University, 1993 pp16-17

5.8 **Rowlands. P**
Reducing Backscatter
http://www.oceanoptics.co.uk/Backscatter.html
13 Northumberland Avenue, London WC2N 5AQ.

5.9 **Calderwood T.D. United States Naval research Laboratory**
Highlights of NRLs First 75 years
United States Naval research Laboratory
Washington,US, October 1998

5.10 **Huggett Q.**
Long Range Underwater Photography in the Deep Ocean
Marine Geophysical Researches
Vol. 12 1990, pp69-81

5.11 **Woods Hole Oceanographic Institution**
The Discovery of Hydrothermal Vents: Trail of Discovery 1972
25th Anniversary CD ROM
Woods Hole Oceanographic Institution 2002

5.12 **Knight I.S**
Laser Scanning Underwater Viewing System With a Wide Field of View Detector
MSc. Thesis, Cranfield University (1993)

5.13 Ocean Engineering and Production
Laser Technology
http://www.hboep.com/laser.html,
Technical data,2003

5.14 Caimi F.M
Laser/Light Imaging for Underwater Use
Sea Technology
(December1993)p23

5.15 M. G.Gibby, J.H.Fahs and M.B Stine
Validation of the Underwater Synchronous Scanner Imaging Model
Arion Systems Inc.
Technical Data August 1991

5.16 Marshall M.
Blue Green Laser Plumb the Mysteries of the Deep
Underwater Imaging,
Laser Focus World
April 1993, pp185-197

5.17 Duntley S.Q.
Underwater lighting by submerged lasers and incandescent sources,
Visibilty laboratory, Scripps institute of Oceanography, Sandiego
California, June1971

5.18 N.E.Johnson
Laser system for underwater observation,
Research / development,
April 1968 pp28- 31

5.19 Heckman Jr.P.J.
Underwater Range Gated photography
U.S. Nava lOrdinance, Test station. Calif.
Technical Publication, No. NOTS TP 4182, Oct 1966
Cited in
S.Tetlow.
Use of laser stripes to reduce backscatter in an underwater viewing system.
Cranfield institute of Technology PhD Thesis 1993 p25

5.20 Parslow G.I.
Development of an underwater laser lined scanning imaging system
Cranfield University 1994
MSc thesis pp33-34

5.21 Jaffe J.S.
Computer modelling and the design of optimal underwater imaging systems
Journal of oceanic engineering
vol 15 No2 April 1990

5.22 M.L.Riaziat, R.X.Cao, L.C.Wong,R.Bourke
Laser Heterodyne imaging for shallow water surveillance.
International society of offshore and polar engineers,
Proceedings of the seventh international polar engineering conference,
Honolulu May 25-30 1997 pp544-549

5.22 K.D.Moore, J.S.Jaffe, B.L.Ochoa,
Development of a new underwater bathymetric laser imaging system: L Bath.
Journal of atmospheric and oceanographic technology
Vol17 2000 pp 1106-1115

5.23 Allwood R.
Lasers: Their Applications in Water, Underwater
Systems design,
Jan/Feb 1985 pp26-28

5.24 Marshall L.R.
Blue-green lasers plumb the mysteries of the deep.
Laser focus world
April 1993 pp185-197

5.25 Golnabi H.
Image evaluation for the synchronised laser scanning systems,
Optics and Laser Technology,
Vol 31, Issue 3 April 1999 pp 225-232

5.26 Caimi F.M., Bessios A.G.
Surface mapping and imaging using low power lasers,
IEEE Oceans 94
Sept. 1994 pp716-721

5.27 Automated Imaging Association,
Machine Vision Online
http://www.machinevisiononline.org 2003

5.28 *A Brief History of Lasers*
Dept. of Mechanical engineering
Columbia University
http://www.columbia.edu/cu/mechanical/mrl/ntm/level1/ch02/html/l1c02s01.html

5.29 Marshall L.R.
Blue-green lasers plumb the mysteries of the deep.
Laser focus world
April 1993 pp185-197

5.30 Miller A., Finlayson D.M
Laser Sources and Applications
Proceedings of the Forty Seventh Scottish Universities Summer School in Physics, St Andrews (1995)

5.31 *Benefits of Diode Pumped Lasers*
CEOLaser.com
Technical Data
http://www.ceolaser.com/benefits-of-DPSS.html

5.31 **Jaffe J.S., Dunn C**
MODEL-BASED COMPARISON OF UNDERWATER IMAGING SYSTEMS,
pp344-362 SPIE Vol 925 Ocean Optics IX 1988

5.32 Spours J.
The Use of a Structured Laser Light System to Ascertain Three Dimensional Measurements of Underwater Work Sights
Cranfield University 2000
PhD Thesis

5.33 Tetlow S.
Development of a Hybrid Laser Viewing System,
Underwater Systems Design (1994)

5.34 Parslow G.I.
Development of an underwater laser lined scanning imaging system
Cranfield University 1994
MSc thesis pp33-34

Section 7

7.1 L.S.Clesceri, A.D.Eaton,
Standard Methods for the examination of Water and Wastewater, 20th Edition ,
American Public Health Association; (January 1999)

7.2 Tetlow S.,
Use of Laser Light Stripes to Reduce Backscatter in an Underwater Viewing System
PhD Thesis, Cranfield University, 1993

7.3 **Spours J.**
The Use of a Structured Laser Light System to Ascertain Three Dimensional Measurements of Underwater Work Sights
Cranfield University 2000
PhD Thesis pp49-52 + 60

7.4 **Abercrombie R.**
Development of an Underwater Laser Imaging System for an Autonomous Underwater Vehicle (AUV)
Cranfield University 1999
MSc thesis pp86-90

7.5 **R. Allwood.**
Lasers:their applications in water,
Underwater systems design
January/February 1985 pp26-28

Section 8

8.1 **Tetlow S.,**
Use of Laser Light Stripes to Reduce Backscatter in an Underwater Viewing System
Cranfield University1993
PhD Thesis,

8.2 **LabVIEW concepts Manual**
National Instruments 2003-04-01
Ni.com

Section 12

12.1 **Abercrombie R.**
Development of an Underwater Laser Imaging System for an Autonomous Underwater Vehicle (AUV)
Cranfield University 1999
MSc thesis pp86-90

APPENDICES

Appendix A

Vision Blox algorithm operator interface

Appendix B

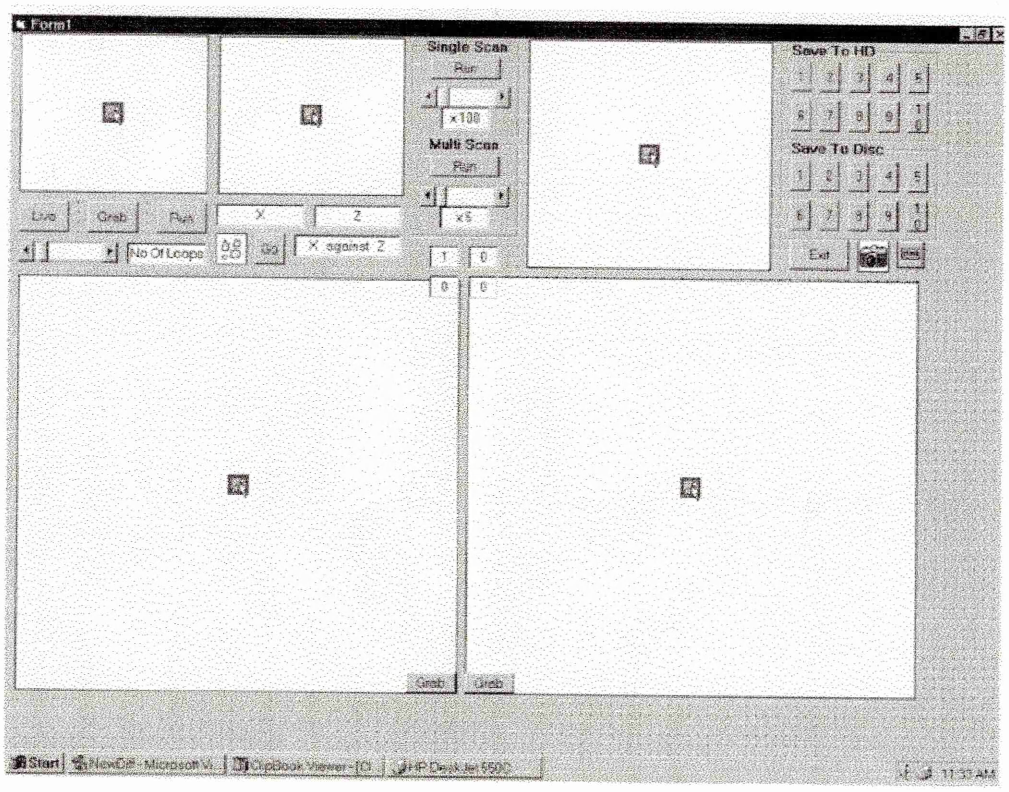
LabVIEW Algorithms

- **Laser Stripe 1a**
- **Minimal gamma**
- **Minimal gamma with popen filter**

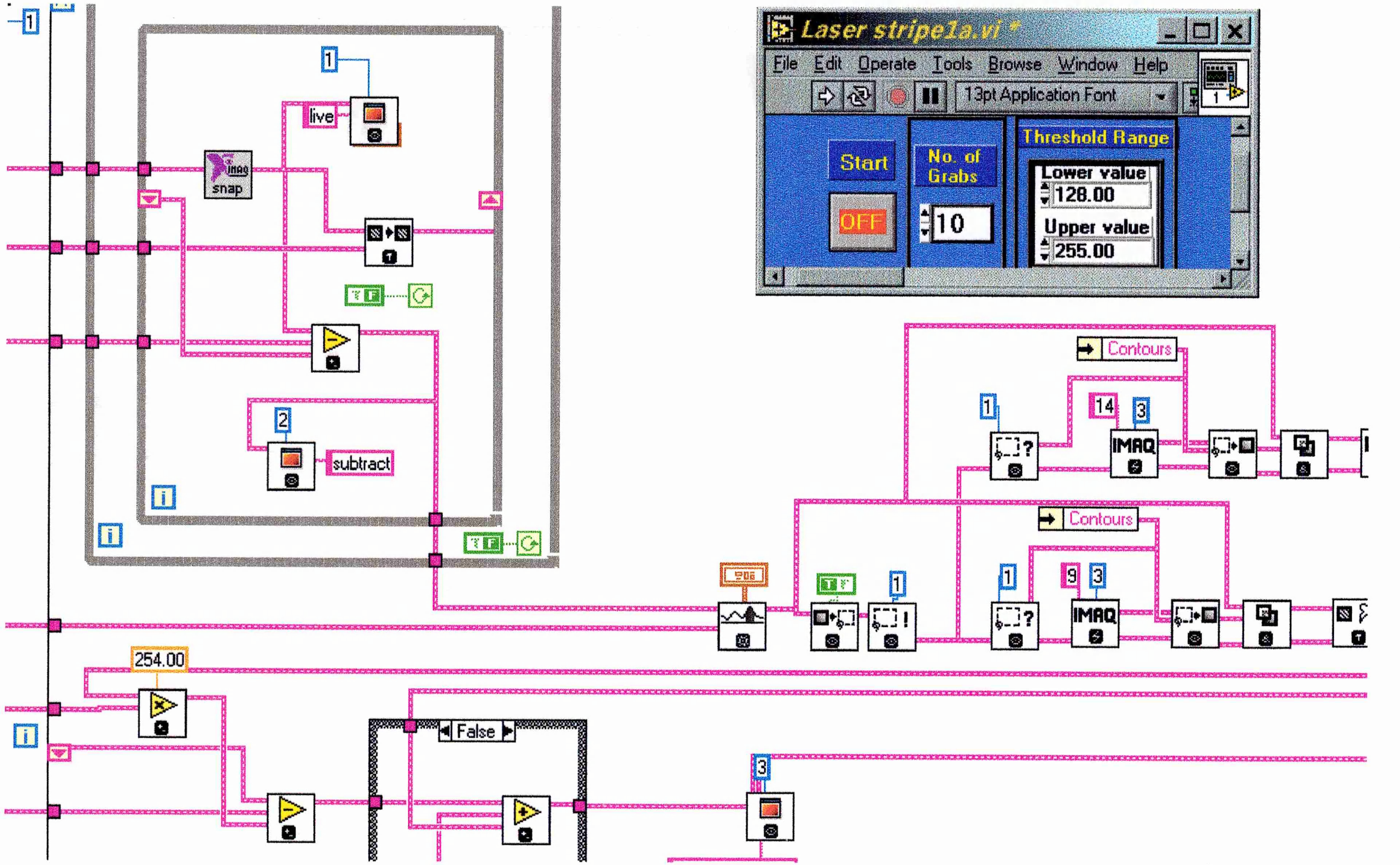
APPENDIX C
ANALYSIS ALGORITHM

- **Intensity measure and histogram**
- **Intensity measure and histogram live**

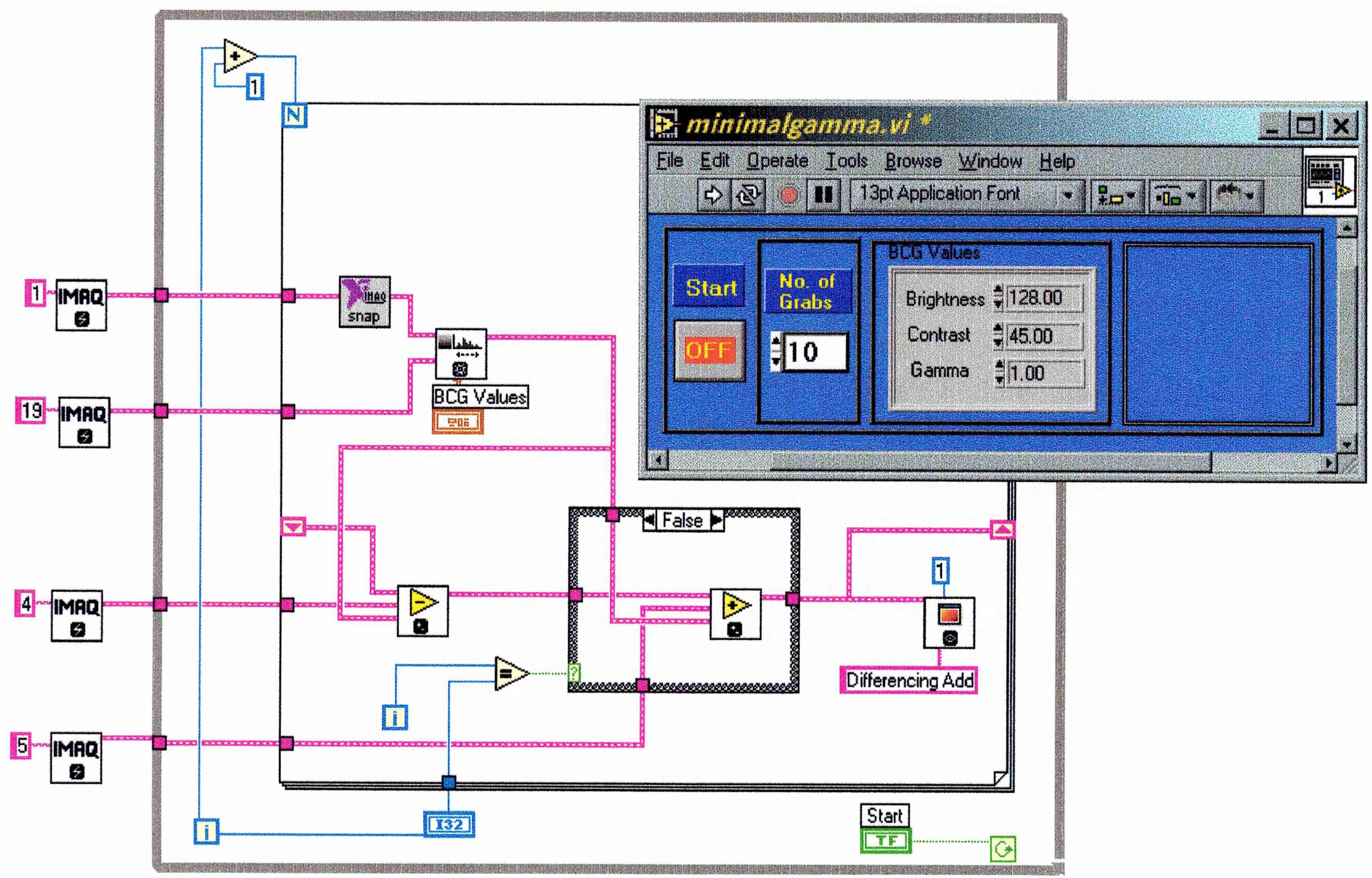
APPENDIX A


Form1
Single Scan
Run
x100
Multi Scan
Run
x5
Save To HD
Save To Disc
Live
Grab
Run
X
Z
No Of Loops
Go
X against Z
Exit
Grab
Grab
Start

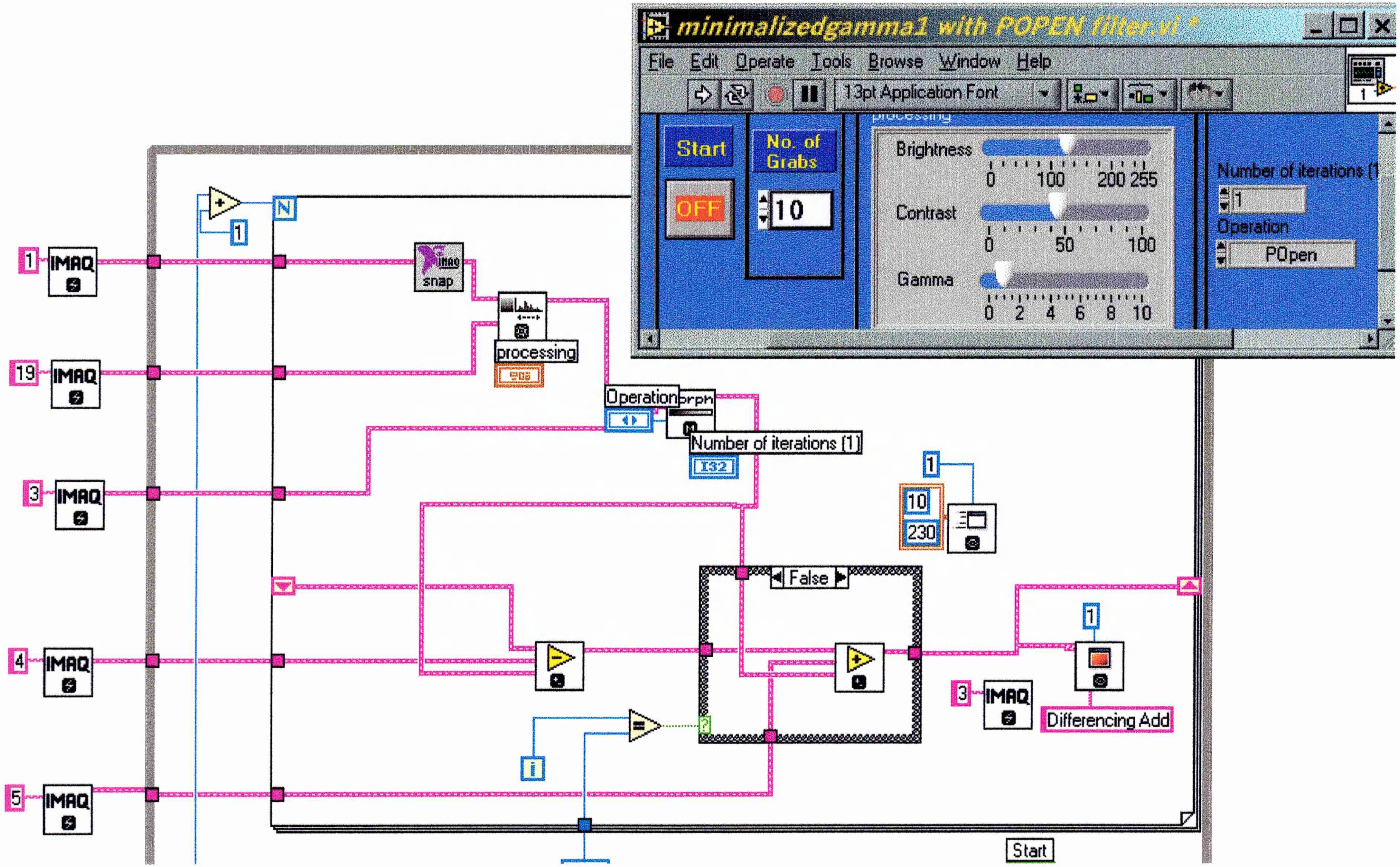
APPENDIX B



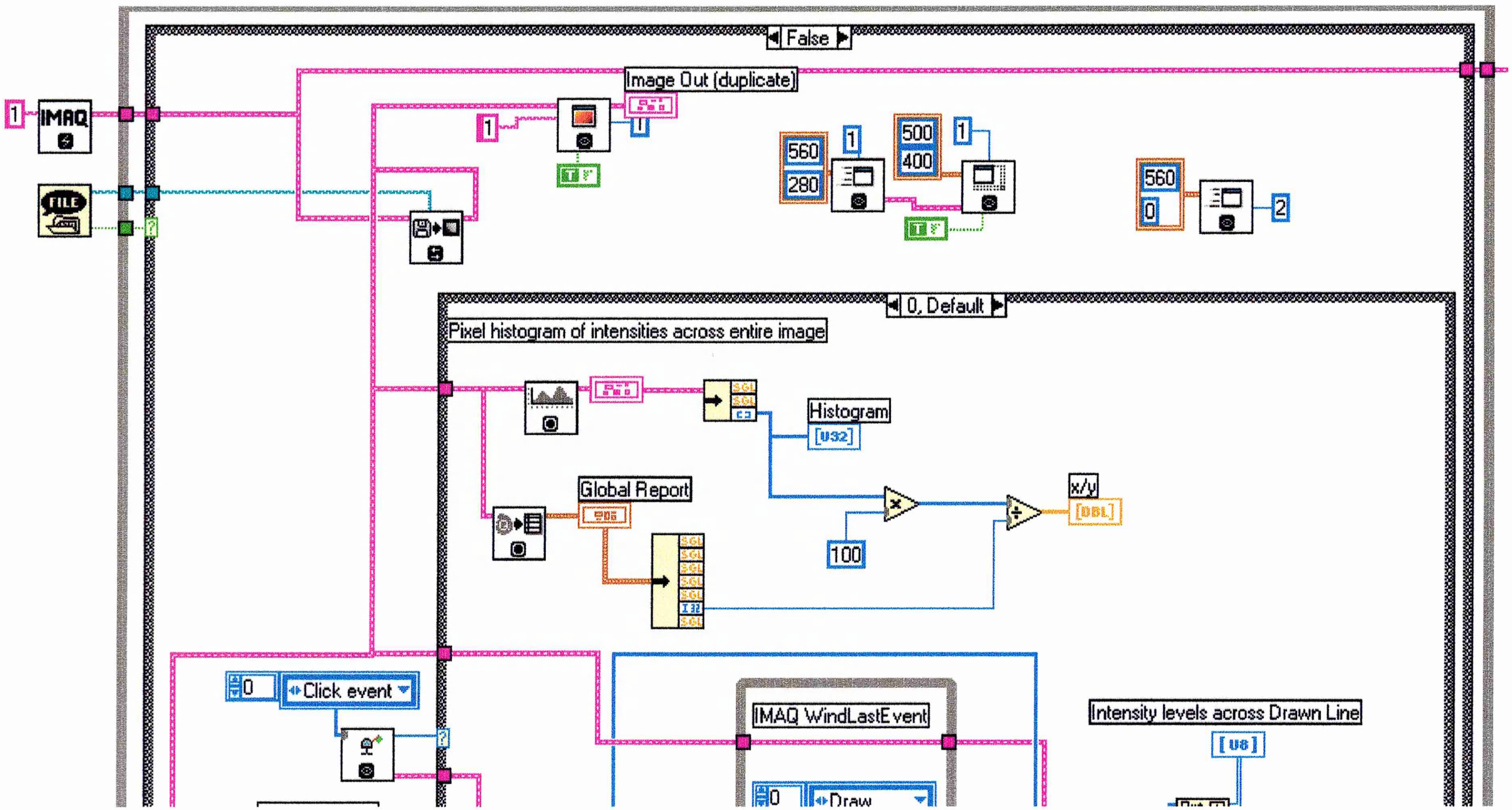
Laser Stripe 1a.vi .vi



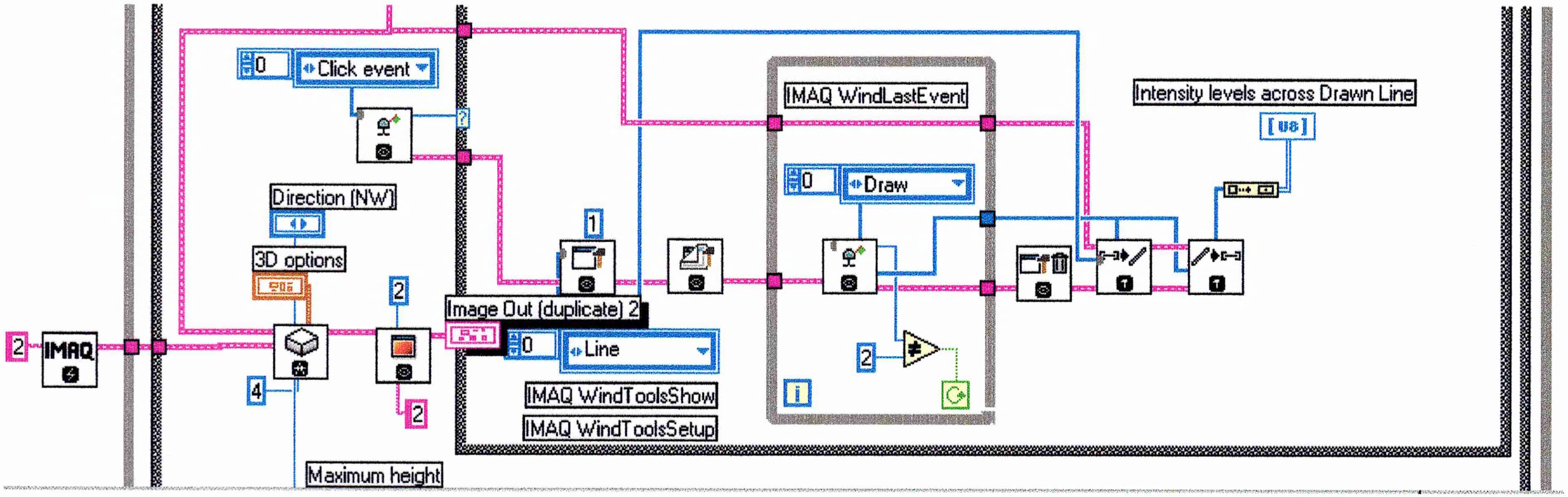
minimalgamma.vi *
File Edit Operate Tools Browse Window Help
13pt Application Font
Start
OFF
No. of Grabs
10
BCG Values
Brightness
128.00
Contrast
45.00
Gamma
1.00
IMAQ
snap
BCG Values
False
Differencing Add
Start
I32


minimalizedgamma1 with POPEN filter.vi *
File Edit Operate Tools Browse Window Help
13pt Application Font
Start
OFF
No. of Grabs
10
Brightness
0 100 200 255
Contrast
0 50 100
Gamma
0 2 4 6 8 10
Number of iterations (1
Operation
POpen
IMAQ
snap
processing
Operation
Number of iterations (1)
I32
False
Differencing Add
Start

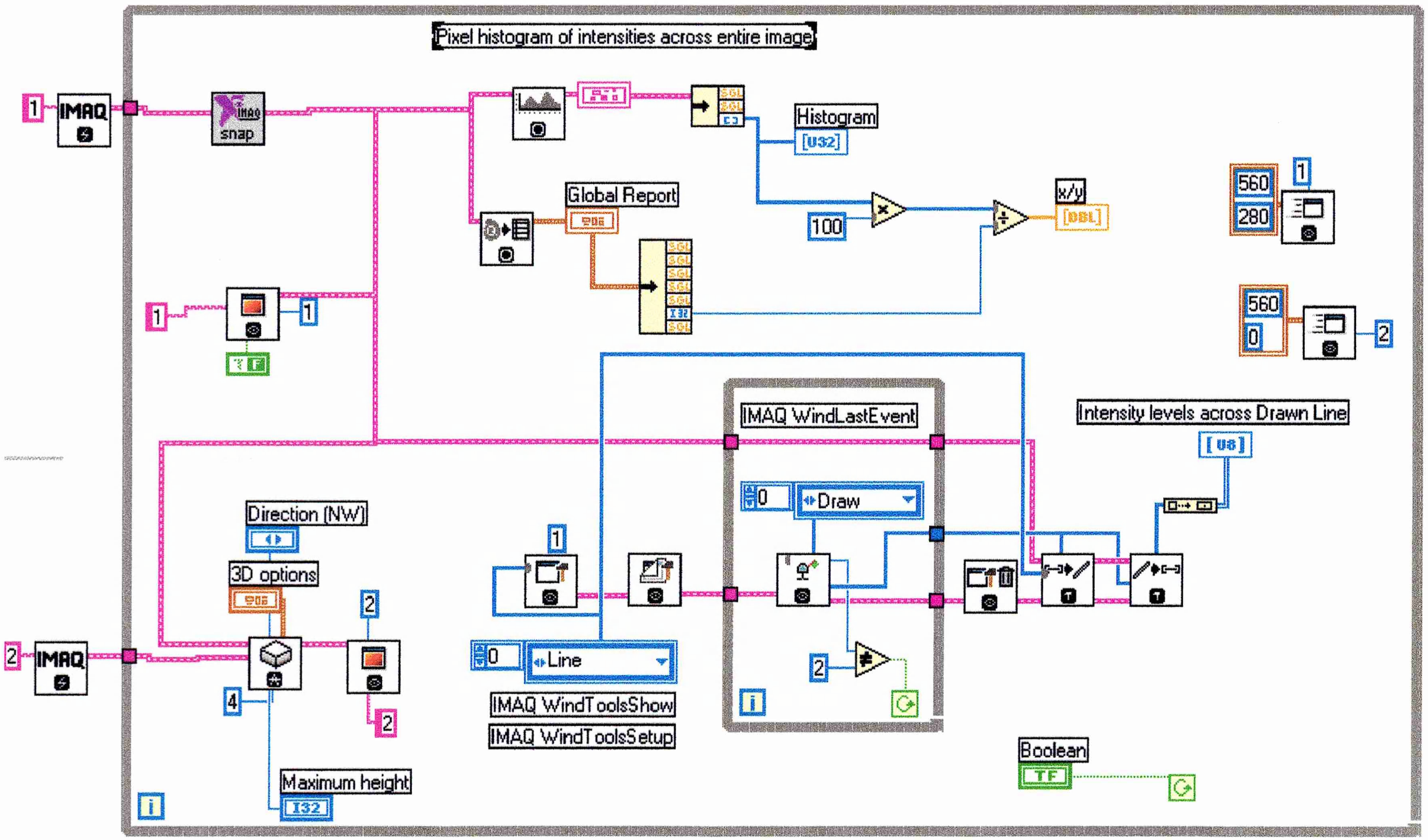
APPENDIX C



Intensity Measure and Histogram .vi (top half)



Intensity Measure and Histogram .vi (bottom half)



Intensity Measure and Histogram Live .vi