CRANFIELD UNIVERSITY

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Advanced Surface Movement Guidance and Control System Investigation and Implementation in Simulation

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ABSTRACT

The Surface Movement Guidance and Control System (SMGCS) is a system providing the surveillance, routing, guidance and control supports to the airport traffic. The moving objects being managed include all the aircraft and vehicles in the interested area on the surface; the personnel making use of this system are the pilots, vehicle drivers, and ground controllers.

The airport surface traffic management has long been discussed because of the operational challenges; this includes the increasing complexity of the field movement management and the density of airport traffic. To improve airport operation qualities, the Advanced Surface Movement Control and Guidance System (A-SMGCS) was introduced. In terms of architecture and capability differences, there are two levels of the A-SMGCS, which are A-SMGCS I & II. The positive impacts on the airport surface operation are: safety, capacity, efficiency, human factor conditions, and economic issues.

This project deals with an investigation on SMGCS baseline and the A-SMGCS, covering the system conception, background, current developments and relative technologies. The applications in practical operations are discussed as well.

There is also an analysis about the airport surface incursion classification and severity. Based on this, a simulation is presented to illustrate the practical applications of the A-SMGCS. The simulation results show the functions of Human Machine Interface (HMI) in A-SMGCS, including the designation and diversion for clearance, the real-time view of surface target movements and the indications for contracted incursions.

Over all, the research aims are to work on an investigation and explanation of A-SMGCS, and to implement a simulation of the system functions. The implementation includes the image processing, system architecture definition in Simulink, Graphical User Interface (GUI) design for the HMI, and the corresponding Matlab programming for simulation environment establishment.

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NOMENCLATURE

ACARS	Aircraft Communication Addressing and Reporting System
ACL	ATC Clearance
ACM	Aircraft Communication Messages
ADS-B	Automatic Dependant Surveillance-Broadcast
AMDB	Airport Mapping Database
AMM	Airport Moving Map
ASDE	Airport Surface Detection Equipment radar
A-SMGCS	Advanced-Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATS	Air Traffic Service
AVOL	Aerodrome Visibility Operational Level
CAF	Clearance Awareness Function
CPDLC	Controller Pilot Data Link Communication
ECEF	Earth-centred Earth-fixed
EMMA	European Movement Management by A-SMGCS
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FIS-B	Flight Information Services –Broadcast
FMS	Flight Management System
GPS	Global Positional Satellite
GUI	Graphical User Interface
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
AWOP	All Weather Operations Panel
ID	Identification
INS	Inertial Navigation System
LAAS	Local Area Augmentation System
LLA	Latitude, Longitude, and Altitude
MLAT	Multi-Lateration
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NED	North-East-Down
ND	Navigation Display
NOTAM	Notice To Airmen
P.I.	Punctuality Index
PSR	Primary Surveillance Radar
RF	Radio Frequency
RGB	Red, Green, and Blue
RVR	Runway Visual Range
RWA	Runway
SMR	Surface Movement Radar

SSR	Secondary Surveillance Radar
STIS-B	Surface Traffic Information Service – Broadcast
TCP/IP	Transmission Control Protocol/Internet Protocol
TWA	Taxiway
UAT	Universal Access Transceiver
VDL	VHF Data Link

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1.1 Project Introduction

1.1.1 Project Aims and Objectives

This project aims to complete the following items relevant to A-SMGCS:

- An investigation into the system concept, including the development background, industry standards, performance requirements, technique significance, function architectures and subsystem structures;
- An analysis for the airport surface traffic condition, focus on the runway incursion estimatition, going together with a FAA Runway Safety Report [1];
- An simulation implementing the main functions required by ICAO A-SMGCS manual [2], covering the AMM display and collision alerting.

To meet the project aims, work items conducted during the study are divided into five main parts:

- Description of the investigation about the A-SMGCS system, including background, development, industry standards, performance requirements, technique benefits;
- Analysis of the airport surface incursions, including the classification of the occurrence cases, and the estimation of the incursion severities;
- Illustration of the ground-onboard A-SMGCS architectures shown by flowchart diagrams, together with the explanations of the basic A-SMGCS functions and algorithms;
- Simulation of the A-SMGCS basic functions; the simulation is based on the A-SMGCS practical operations identified previously, and presented in an AMM display.

- Evaluation of the progresses and the limitations based on the project achievements, bringing forward several possible expanding in the future work.

By understanding the survey of practical surface movement operational technologies and the accidents records extracted from FAA and ASRS report, the taxiway and runway accidents are divided into different cases and levels, which is the application environment of the A-SMGCS functions.

The next step introducing the system architecture and its working principles demonstrates the A-SMGCS basic functions. The system discussed in this part belongs to A-SMGCS Level 2.

The implementation algorithm is based on the airport surface incursion definition and the A-SMGCS functions, generating the results as following:

- The AMM for pilots and ground controllers;

- The airport surface clearance setting window as the ATC HMI.

The simulation results illustrate the basic A-SMGCS HMI operations and AMM scenarios, coming to a conclusion covering the project achievements and limitations.

The last part of the work is to demonstrate the possible developments for the current achievements, in terms of:

- The supplementations to the system function implementations, simulating system performance more precisely and practically;

- The extension for the aircraft operation phases, from the ground movement to the flight.

1.1.2 Project Tasks

Four main tasks are conduct in the project.

- Preliminary work: A review of existing work and literature in the field of study, and the selection of the airport with existing surface paths have been undertaken.

- Airport traffic condition analysis: To define the vehicle traffic within the move area, especially identifying the classifications and the severity levels of the surface incursions.

- System establishment: the A-SMGCS layout and block diagrams have been built, implementing surveillance approaches, data processing, information transmission, and terminal HMI.

- Function simulation: Based on the established system architecture and function definitions, the simulation of airport surface operation and possible collision occasion has been implemented to illustrate the basic system HMI and AMM display scenarios.

1.1.3 Overview of Report Chapters

The following is a brief description of the contents of each chapter in this report.

- Introduction: A brief introduction about the A-SMGCS background, and the corresponding project structure.

- A-SMGCS main supporting technologies: Introduction for existing technologies and the work carried out on the related simulation.

- Accidents Analysis and Classifications: The conclusion of the existing statistical documents about accidents happening during the latest two decades, followed by extraction of typical incident cases. The accidents are divided into geometrical classifications and severity levels.

- System Functions Configurations and Architectures: The establishment of a flowchart diagram of the system function. The system functions and workflows are described here correspondingly.

- Simulation Implementation: The introduction of the simulation software employed and the implementation flowchart.

- Simulation Results: To present the progress made in the simulation, including the models, GUI interface, and the corresponding AMM display scenarios.

- Conclusion: The conclusion of the work completed currently, and an discussion about possible future work related to the project.

1.2 Project Background

During the latest decades, the global air transportation industry has been experiencing sharp growth, and due to the increasing traffic density, airport management capability faces huge challenges of congestions and incursions, combined with the complexity of airport operation, which leads to unforgiving errors made by pilots, ground controllers and surface vehicles drivers. This produces an airport movement record far from safe-critical. The NAS continue to experience approximately one runway incursion per week, which is classified as significant or a barely avoided collision (FAA 2004) [1].It is estimated that for every 350,000 surface traffic one severe runway incursion occurs and for every 66 million movements one accident is caused by runway incursion. With 18 million movements on the ECAC airports per year, this results in one runway incursion related accident every 3.7 years.

Traditionally, the pilots follow the radio communication navigations from the ground controllers via preset radio channel to route the surface movement, combining with an airport routing point paper chart in the cockpit. The pilots and vehicle drivers judge the surface traffic by visual signals, such as airfield markings (e.g. painted central lines), lightings, and signs. As a result, the weather conditions can significantly affect their capabilities of these agents to “see and be seen”. Meanwhile, the movement controllers rely on the pilots' reports and the surface radar to monitor the surface spacing and potential incursion. Consequently for the ground controllers there are two main difficulties in their jobs:

- To memorize the routing navigations given to the pilots;
- To deliver the real-time emergent path change to the pilot if it is necessary.

Meanwhile for the pilots, vehicle drivers, and controllers, there are no prescribed separation minima, and they have to share the responsibilities of avoiding surface incursions.

All airports have some sorts of SMGCS. As shown in the Manual of Surface Movement Guidance and Control Systems (SMGCS) [2], the system performances include guidance and routing for aircraft and field vehicles. The simplest SMGCS provides painted guidelines and signs as navigating guidance, while the most complex form consists of switched taxiway centre lines and stop bars which accomplish the routing functions.

Under the SMGCS, the control to the pilots and vehicle drivers are usually provided from the air traffic controllers next to the operating areas, by sending traffic directions though voice communication. Meanwhile, the airport controllers receive movement awareness from pilots' reports and radar, such as SSR (Secondary Surveillance Radar) and Surface Movement Radar (SMR). Under low-visible weather conditions, the SMGCS provides plans to direct the surface movement. Furthermore, depending on the regulations and policies in Air Traffic Service (ATS), the organizational responsibilities, and the configuration and facilities in the airport, SMGCS provides the operation procedures specific for each airport.

However, without practically effective means of cooperative surveillance, the SMGCS does not support enough satisfying capabilities to identify the positions and movement of aircraft and vehicles in interested areas, and relevantly there are no automatic potential incursion alerts based on spacing monitoring, which leads to a surface traffic safety situation far from the required level.

Firstly, the pilots and vehicle drivers lose their judgments about the ownship movement and possible intruders as accurate as in ideal visual circumstances.

Furthermore, the controllers suffer overload navigation work of collecting movement information and arranging the routing. In addition, due to limitation of voice communication Bandwidth and transmission speed, the information transmitting congestion causes negative impacts on the deliveries of control directions or the modification of them.

The traditional SMGCS operational method leaves chance to several elements to generate negative effects on airport traffic .The weather condition, such as rain, fog or darkness, might lead to airport movement delay or incursions, and consequently seriously impact the airport surface movement efficiency and safety.

Regarding the human factor, the overload for both the pilots and ground controller is increasing with the traffic pressure growth, which could result in higher risks of human errors relative to incursions.

Taking the capability of radio communication into account, the requirement for real-time transmission of routing navigation switching can be difficult to meet due to the frequency of band congestion or unstable signal quality. In the case of airport vehicle traffic, the possibility of delay and incursions also exist due to the traditional operation.

The mentioned problems generate not only low-efficient surface movement, but also serious incidents and accidents. To meet the requirement of preventing the runway incursions and improving the airport surface operating capabilities, NASA and its partners have developed an advanced surface movement guidance and control system (A-SMGCS), including both the architecture and operation procedure of the system.

2 Literature Review

2.1 Industry Regulations

From the definition of ICAO [2], the A-SMGCS level function includes four parts, which are guidance, surveillance, control, routing. Guidance is the function that provides navigation information to the aircraft on the airport surface. The surveillance function provides a position report of all aircraft within the movement area. The Air Traffic Control (ATC) function provides the conflict resolutions. The routing function designates the route for each aircraft or vehicle on the movement area. [3]

The general and specific requirements for presumption A-SMGCS conform to SES Interoperability Regulation 552/2004 [i.1] as amended by Regulation 1070/2009 [i.5]. The definition of the A-SMGCS level 2 is covered by “part 2: Community Specification for application under the Single European Interoperability Regulation EC 552/2004 for A-SMGCS Level 2 including external interfaces” in the present document. [4]

Based on the ICAO Journal, Monthly Supplement to the Catalogue of ICAO Publications and the Audio-visual Training Aids, the A-SMGCS Manual offers description about this technology including background, development, specific requirements and implementation issues. To improve the SMGCS, A-SMGCS makes use of advanced surveillance technologies, such as Automatic Dependant Surveillance-Broadcast (ADS-B) and Global Position System (GPS). This allows the aircraft movement identifications and proximity indications on an Airport Moving Map (AMM), under wide range of weather conditions. Beyond voice traffic control, by comprehensively working with ground-onboard data-link communication system, the A-SMGCS performs control functions on AMM for the controllers and pilots, including the surface traffic awareness, guidance navigation, and routing direction.

The A-SMGCS Level 1 enables the pilots and ground controllers to be aware of the aircraft and vehicle positions, movement, and cooperative traffic conditions.

Level 2 of the system covers the level 1 capability, and uses the surveillance database to generate automatic alerting. This is generated in case the situation in the interested area violates the rules set within the database.

2.2 A-SMGCS Impact Analysis

In the European Movement Management by A-SMGCS (EMMA) report Indicators and Metrics for A-SMGCS [4], the impact categories considered in the V&V (verification and validation) of EMMA relate to:

- Safety,
- Capacity,
- Efficiency,
- Human factors,
- Costs & benefits.

The first four items are considered as “primary impacts”, while the last item is considered as “derived impacts”.

The airport capacity is identified with the capacity of the most constraining airport sub-system (runway, taxiway, and apron) as following:

- Sustained Runway Capacity: Maximum runway throughput, or flow rate, which can be achieved over a sustained period of time when aircraft operate under IFR, under specific traffic mix, with good ATM/runway system management, in accordance with safety standards and recommendations, and with an acceptable maximum delay for a limited period of time (to be defined locally).[5]

- Sustained Taxiway Capacity: Maximum taxiway system throughput, or flow rate, which can be achieved over a sustained period of time when aircraft operate under specific traffic mix, in accordance with safety standards and recommendations, existing taxiway system management, and with an acceptable maximum delay for a limited period of time (to be defined locally). [5]

The airport efficiency increase contributed by A-SMGCS is analyzed by regarding the aspects as following:

- Delays:
  a) Departure delays:
     1) Per flight: taxi-out delays; push-back delays; start-up delays; departure queuing delays;
     2) Per airport: Mean departure delays.
  b) Arrival delays:
     1) Per flight: taxi-in delays; arrival queuing delays;
     2) Per airport: Mean arrival delays.
- Punctuality Index
- Percentage of operations performed within the agreed / tolerated delay limits (to be defined for each case / site).
- Number of Aircraft waiting in the Departure Queue
- Aircraft or vehicles
  a) Number of mobiles on time arrivals;
  b) Average delay of arrivals.
- Workload
  a) The amount of communication that a controller does per hour.
  b) Average lasting time of those communications.
  c) Number of events and actions that a controller does per hour.
  d) Average lasting time of those events and actions.

According to EUROCONTROL's document "The Human Factors Case: Guidance for Human Factors Integration" [6], the A-SMGCS needs to meet the human factor requirements and contribute to the improvement aspects relevant to:

- Situation Awareness;
- Task achievement;
- Errors;
- System usability;
- Satisfaction level;
- Mental Workload;
- Crew task sharing;
- Global integration (cockpit philosophy consistency).

Considering the entire economic life of the system, the EMMA A-SMGCS defines the cost elements into four major cost categories:

- Cost Category 1: Planning and Design Costs
- Cost Category 2: Development Costs
- Cost Category 3: Operation and Maintenance Costs
- Cost Category 4: Termination Costs

Table 2-1 Indicators and metrics for assessment of EMMA A-SMGCS benefits [4]

Indicator Title	**Indicator Definition**	**Set of experimental conditions**
Energy	savings Monetary savings from reduction in fuel use	Baseline vs. ASMGCS I & II

Indicator Title	Indicator Definition	Set of experimental conditions
Time savings for airlines	Monetary savings from reduction in time spent on the manoeuvring area	Baseline vs. ASMGCS I & II
Airport throughput	Monetary benefits from increase in airport throughput	Baseline vs. ASMGCS I & II
Time Savings for passengers	Monetary savings from the reduction of the passenger delays	Baseline vs. A-SMGCS I & II
Safety impacts	Monetary savings emerging from the improvement of the safety	Baseline vs. A-SMGCS I & II
Reduction of Environmental impacts	Monetary savings from the mitigation of environmental impacts	Baseline vs. A-SMGCS I & II

2.3 Performance Requirements

With the purpose of providing practical “gate-to-gate” airport movement operations, the A-SMGCS should be able to support authorized aircraft and vehicles to perform safe and efficient movement through the whole procedures on the movement area.

From the A-SMGCS Manual [2] and the ICAO Operational Requirements for A-SMGCS Document [3], an A-SMGCS should support the following primary functions:

- Surveillance;

- Routing;
- Guidance;
- Control.

The surveillance function of an A-SMGCS should:

- Provide accurate position information on all movements;
- Provide identifications and labelling of authorized movement;
- Cope with moving and static aircraft and vehicles within the coverage area of the surveillance function;
- Be capable of updating data needed for the guidance and control requirements both in time and position along the route;
- Be unaffected by operationally significant effects such as adverse weather and topographical conditions.

The routing function of an A-SMGCS should:

- Be able to designate a route for each aircraft or vehicle within the movement area;
- Allow for the change of destination at any time;
- Allow for the changes to routing;
- Be capable of meeting the complications related with traffic density and path layout complexity ;
- Not constrain the pilot's choice of a runway exit following the landing.

The guidance function of an A-SMGCS should:

- Provide guidance necessary for any authorized movement and be available for all possible route selections;
- Provide clear indications to pilots and vehicle drivers to allow them to follow their assigned routes;
- Enable all pilots and vehicle drivers to maintain situational awareness of their positions on the assigned routes;
- Be capable of accepting a change of route at any time;
- Be capable of indicating routes and areas that are either restricted or not available for use;
- Allow monitoring of the operational status of all guidance aids;
- Provide online monitoring with alerts where guidance aids are selectively switched in response to routing and control requirements.

The control function of an A-SMGCS should:

- Have a capacity sufficient for the maximum authorized movement rate (dynamic capacity);
- Have a capacity sufficient for the aerodrome planning of requested movements for a period of up to one hour (static capacity);
- Detect conflicts and provide resolutions;
- Be able to provide longitudinal spacing to predetermined values of:

  1) Speeds;

  2) Relative directions;

  3) Aircraft dimensions;

  4) Jet blast effects;

5) Human and system response times; and

6) Deceleration performances;

- Provide alerts for incursions onto runways and activate protection devices (e.g. stop bars or alarms);
- Provide alerts for incursions onto taxiways and activate protection devices (e.g. stop bars or alarms);
- Provide alerts for incursions into critical and sensitive areas established for radio navigation aids;
- Provide alerts for incursions into emergency areas;
- Be capable of incorporating computer-aided management tools;
- Keep controllers, pilots and vehicle drivers in the decision loop;
- Control movements within a speed range so as to cover the operations in all required situations,
- Taking into account the type of movement;
- Be capable of allowing operations in all visibility conditions down to the Aerodrome Visibility Operational Level (AVOL);
- Be capable of allocating priorities to control activities.[2]

2.4 A-SMGCS Main Supporting Technologies

To provide approaches to more controllable and automatic airport operations, the A-SMGCS works with integrated subsystems and technologies. As shown in Table 2-2, the technologies incorporated into the A-SMGCS include:

- GPS;
- ADS-B (only available for aircraft equipped ADS-B);

- Primary Surveillance Radar (PSR) in most of the airports;
- Secondary Surveillance Radar (SSR) providing independent surveillance information.
- The AMM display, working with Airport Mapping Database (AMDB), located in cockpits and ground stations as the terminal HMI unit component.
- Data link communication bands, such as Controller Pilot Data Link Communication (CPDLC) and Surface Traffic Information Service – Broadcast (STIS-B), contributing the digital signal transmitting between surface vehicles or vehicles and ground stations.

Table 2-2 Surface movement management technologies[9]

Function	Aircraft Technologies	Airport Technologies
ownship Position Awareness	GPS, AMDB, Display	---
Traffic Position Awareness	GPS, AMDB, Display ADS-B, STIS-B	AMDB, Display ADS-B, STIS-B, Radar
Route Awareness	AMDB, Display CPDLC	AMDB, Display CPDLC
Route Deviation Detection	GPS, AMDB, Display CPDLC	Display CPDLC
Runway Incursion Detection	GPS, AMDB, Display ADS-B, STIS-B	AMDB, Display ADS-B, STIS-B, Radar

The functions performed from these technologies are described in the following subsections.

2.4.1 Surveillance

Table 2-3 illustrates the categories and technical characteristics of A-SMGCS surveillance technologies.

For SMGCS, the main resources of vehicle positions and identifications on surface are from the SSR and the SMR. Working in Modes 3/A and C, SSR provide aircraft position and identifications based on the replies to the interrogations. SMR transmits a Radio Frequency (RF) signal, then receives and analyze the reflected rays to define the position of the objects in the airport and its circumstance.

SSR and SMR are not for a comprehensive airport environment, especially when there is a high traffic density with targets closed to each other. Therefore in applications regarding surface movement guidance and control, they meet some practical problems.

Table 2-3 Surveillance Technology Category [9]

Type	Independent?	Cooperative?
Primary surveillance radar (PSR)	Yes: surveillance data derived by radar	No: does not depend on aircraft equipment
Secondary surveillance radar (SSR)	Yes: surveillance data derived by radar	Yes: requires aircraft to have a working ATCRBS transponder
Automatic dependent surveillance (ADS-B)	No: surveillance data provided by aircraft	Yes: requires aircraft to have working ADS-B function

For SMR:

- When two vehicles are too closed to each other, they can be seen as only one.
- Very large targets (i.e. B747) can be seen as several separated ones.
- The aircraft identifications are not provided.

For SSR:

- The antenna period (and the information update) is around 4 sec., which is not efficient enough for the application.
- Many aircraft usually turn-off their transponders after landing, so the coverage of identification monitoring is reduced.
- Vehicles are usually not equipped with Mode 3/A/C transponders.

For both SSR and SMR:

- The system performances are sensitive to weather conditions, leading to the problem that when movement information becomes more necessary, the monitoring gets poorer.
- Extra reflections are generated from airport buildings.
- Blank zones can be generated by the radar position and the airport layout.

As mentioned above, the SMGCS systems, based on several monitoring means, does not have the capability to provide accurate position and identification information. Nowadays, the source of reliable identifications and position information is expected to be the Automatic Dependent Surveillance-Broadcast (ADS-B) system. ADS-B uses a global navigation satellite system to gain the information about the ownship position and other relevant information. Meanwhile it broadcasts this information to potential ground stations and other aircraft. The ADS-B signals are transmitted though data-link. The data-link communication technologies applied into ADS-B include Mode-S Extended Squitter (1090 ES) operating at 1090 MHz, Universal Access Transceiver (978 MHz UAT), and VHF data link (VDL Mode 4).

The STIS-B is a supplementary service for ADS-B in an airport where not all aircraft are equipped with ADS-B. From ground stations to the onboard personals, the STIS-B provides the onboard personals with complete surface movement awareness from ground stations. Beside the traffic information, the STIS-B also supports the delivery of alerts generated on ground. STIS-B station transition is able to work on the ADS-B data link.

GPS (Global Position System) is installed on aircraft to provide tracking reports by making use of a satellite network. Some common satellite networks include Iridium, Globalstar and Inmarsat. Operating cooperatively with ADS-B, Aircraft situational awareness supported by GPS contributes to reliable and efficient aircraft surface movement information reports. The contents of it could include position, velocity, heading and turning rate. These systems have varying configurations for reporting intervals, typically from one-minute to fifteen-minute time intervals.

2.4.2 Data-link Communication

Basically, the audio communication is the main means for airport surface routing and control, and nowadays it is supplemented by data communication. Mostly, the data link provides transmission of GPS, ADS-B and STIS-B signals; in A-SMGCS the ATC could utilize data link to send surface traffic control messages.

The CPDLC is a method by which air traffic controllers can communicate with pilots over a data link system. In A-SMGCS, CPDLC is utilized to support ATC Clearance (ACL), Aircraft Communication Messages (ACM), ADS-B surveillance information, and the automatic uplink of the SSR transponder code into the cockpit. A-SMGCS information transmitted over CPDLC includes monitor message, route clearance uplink, 2-4 Dimension trajectories, continuous descent approaches, and constraint coordination as well.

The other main data link communication means in A-SMGCS is the Universal Access Transceiver (UAT). The UAT system is specifically designed for ADS-B operations and nowadays is the only ADS-B link standard that is truly bi-directional. There is also access for UAT users to Flight Information Services – Broadcast (FIS-B) and STIS-B through a multilink gateway.

2.4.3 Display

The necessary A-SMGCS information for ground controllers and pilots is displayed in a color graphical form and shown into several pages which follow assigned priority. The display pages are named AMM, as mentioned in Chapter 1.2.1.

First of all, traffic in the operational airport ground and in the takeoff or landing phases are displayed in the AMM, such as runways in use, runway/taxiway closures (Figure 2-1), and other information typically contained in Automatic Terminal Information Service (ATIS) transmissions (voice or digital) and NOTAM (Notice To Airmen). Furthermore, the takeoff or landing runway selected in the FMS flight plan is highlighted by a white outline on the AMM (Figure 2-1/ Figure 2-2), which reminds the crew of the FMS settings and aims to avoid the takeoff and landing on the wrong runway. In addition, the Clearance Awareness Function (CAF) was conceived to raise the crew’s awareness of clearances assigned by ATC, mainly by presenting the assigned taxi route (see from Figure 2-3). The primary achievement of preventive alerting is to avoid ownship runway incursions.

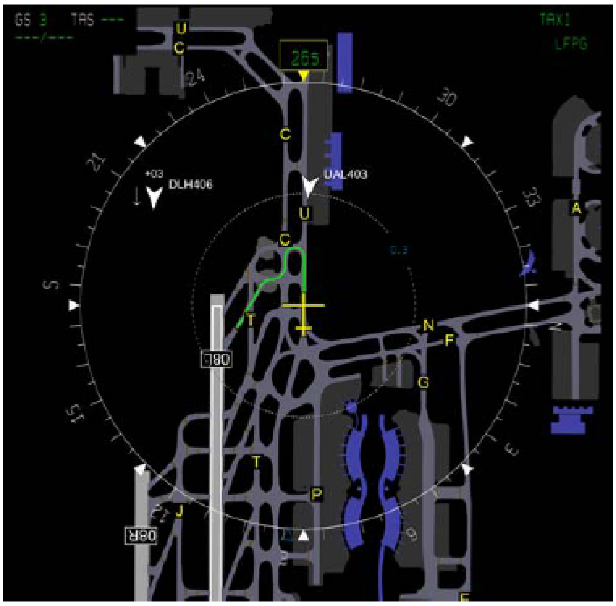


Figure 2-1 Integrated representation of closed runways and taxiways on the AMM [10]

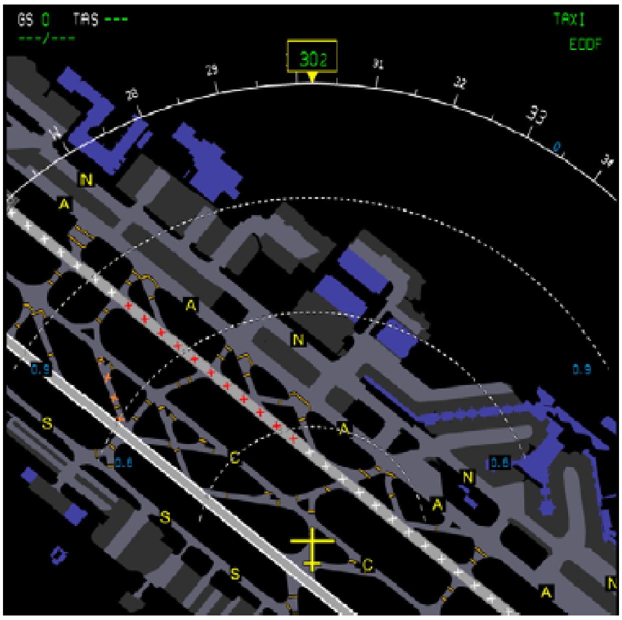


Figure 2-2 Visualisation of traffic, FMS-selected runway and assigned taxi route on the AMM [10]

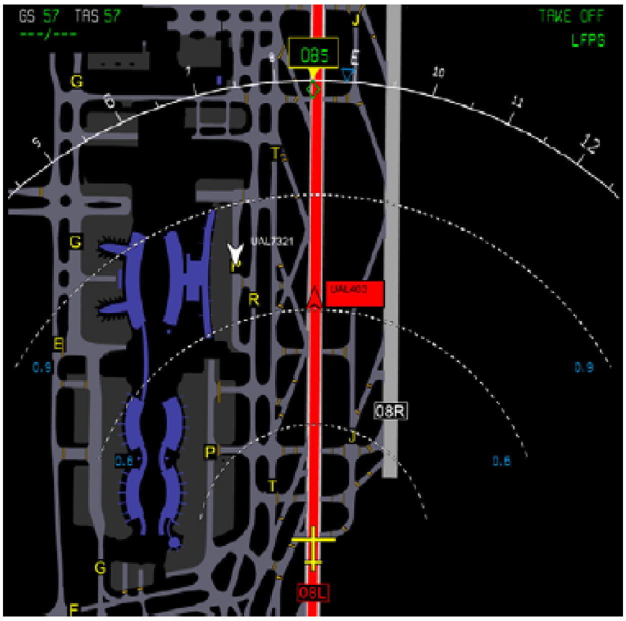


Figure 2-3 Visualisation of runway incursion alert [10]

2.4.4 HMI for Clearance Assigning

Under the conventional SMGCS, ATC controllers get awareness of the airport traffic by surface radar surveillance signals and pilot report. The ATC controller commands are sent by radio communication. As improvements both the ground controlling and onboard operation could benefit from, the A-SMGCS provide integrated displays for ground and onboard operating personnel.

Taking advanced surveillance signals as input and through data and image processing, the display is capable to support real time view covering the whole surface traffic situation. The displays, located in ATC station operation desk or cockpit, are accessible and understandable according human machine interface considerations.

Figure 2-4 A-SMGCS display on the ground control desk

To reduce the workload of sending airport ATC commands by radio communication, and avoid the command delivery delay caused by communication congestion, A-SMGCS supports the controllers to set surface clearance from digital interface on integrated display. After fixing the clearance for one target, the plan is sent to it through data link communication path which enables information transmission to be more reliable and efficient.

2.5 Accidents Analysis and Classifications

2.5.1 Official Surface Incursion Definition

As identified in FAA Runway Safety Report (2004) [1], there are following definitions related to a surface traffic safety issue:

- A collision hazard is any condition, event or circumstance that could induce an occurrence of a collision or surface accident or incident.
- A loss of separation is an occurrence or operation that results in less than the prescribed separation between aircraft, or between an aircraft and a vehicle, pedestrian, or object.
- A surface incident is any event where unauthorized or unapproved movement occurs within the movement area or an occurrence in the movement area associated with the operation of an aircraft that affects or could affect the safety of flight.

A surface incident can occur anywhere on the airport's surface, including the runway. All runway incursions are surface incidents, but not all surface incidents are runway incursions. To be identified as a runway incursion, the movement must encounter the following conditions:

- At least one aircraft, vehicle, pedestrian, or object must be on the runway;
- A collision hazard or a loss of separation must occur.

A runway incursion, and expanded as surface incursions, is any occurrence on the airport runway environment involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of required separation with an aircraft taking off, intending to take off, landing, or intending to land.

In FAA definition, an occurrence is:

- A pilot deviation: any action of a pilot that results in violation of a Federal Aviation Regulation (FAR);
- An operational error: a failure of the ATC that results in a loss of separation;
- A vehicle or pedestrian deviation: a vehicle operator, non-pilot operator of an aircraft, or pedestrian deviating onto the movement area, including the runway, without ATC authorization.

The FAA further classifies a surface incident as either a runway incursion or a non-runway incursion (Figure 2-5).

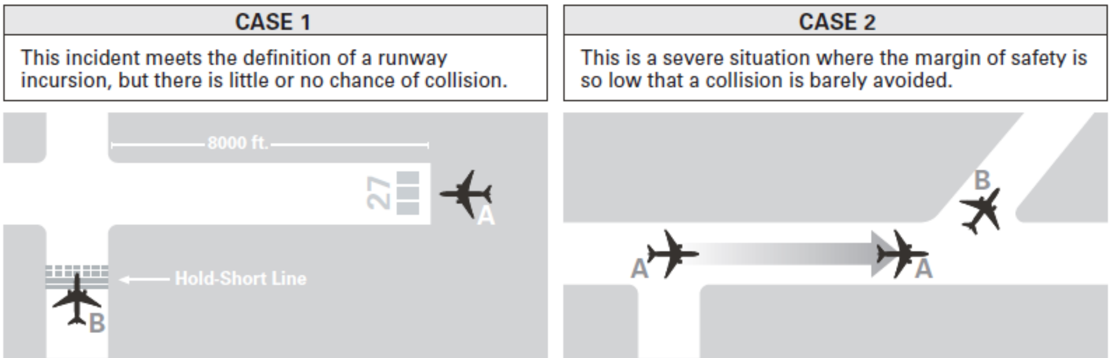


Figure 2-5 Runway and non-runway incursion [1]

The simulation for the surface incidents, covering runway incursion and taxiway incursion, are presented in Chapter 6.

According to the ICAO A-SMGCS manual [2], the incursion is 'any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected areas of a surface designated for the landing, take-off, taxiing and parking of aircraft'.

2.5.2 Incursion Statistics and Error Sources Analysis

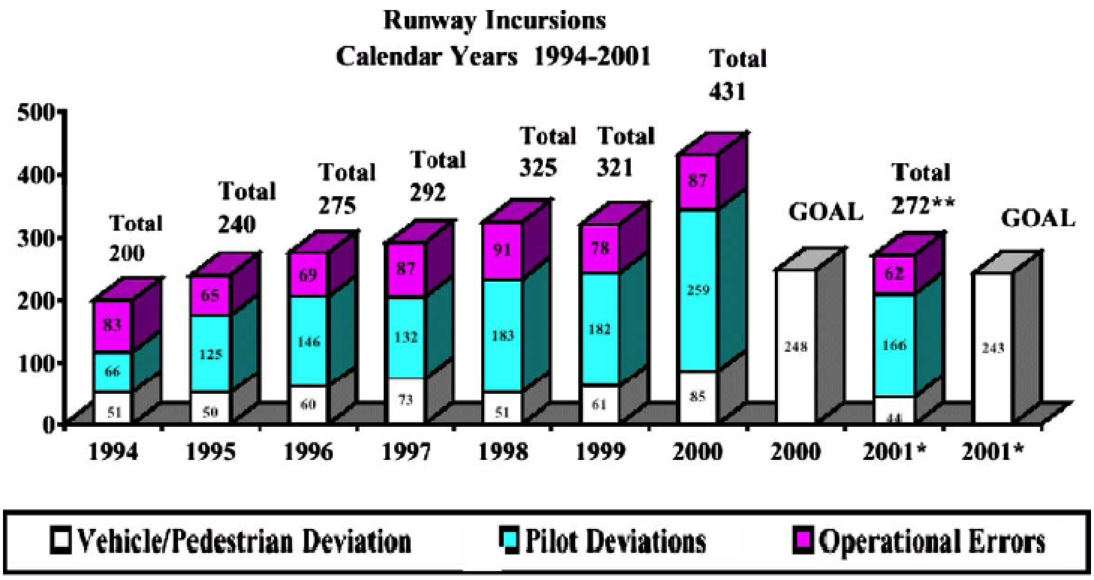
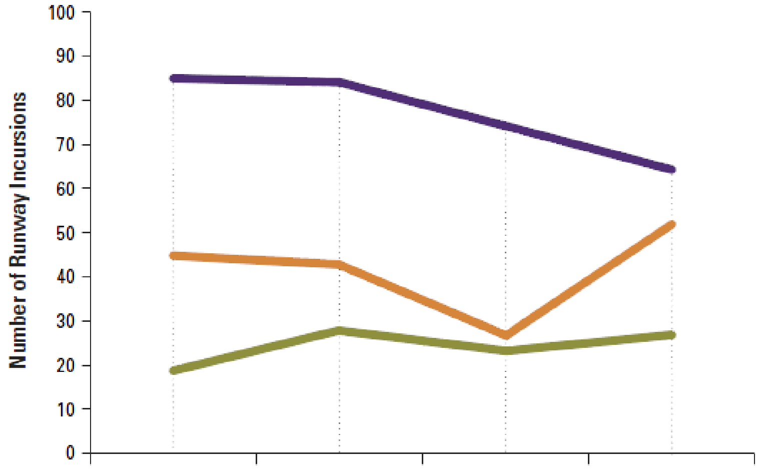


Figure 2-6 US runway incursions form 1994-2001[11]

Figure 2-6 illustrates the results of a study on runway incursion in the US from 1994 to 2001; regarding human factors (Distraction, forgetfulness, or misunderstanding), there are causal factors contributing to this number:

- Pilot deviations;
    1) Miss out on some portion of taxi instructions;
    2) Take a wrong turn;
    3) Surpass a designated hold-point.
- Operational errors;
    1) Issues a clearance with wrong receiver or content;
    2) Fail to check/correct incorrect read-back from pilot/ driver.
- Vehicle or pedestrian deviations.

Figure 2-7 shows the statistic data of runway incursion during 2000-2003.



	FY 2000	FY 2001	FY 2002	FY 2003	Total
Pilot Deviations	85	84	74	64	307
Operational Errors/ Deviations	45	43	27	52	167
Vehicle/Pedestrian Deviations	19	28	23	27	97
					571

Figure 2-7 Number of Runway Incursion Types Involving At Least One Commercial Aviation Aircraft [1]

Besides human factor effects, the communication gap also influents the surface movement safety because of:

- Frequency congestion;
- Long sequence of taxi instructions during landing phase;
- Non-standard terminology.

2.5.3 Incursion Geometry Classifications

To make the incursion definition more specific and practical, the categories of the process of movement are identified as illustrated in Figure 2-8: A (arrival), D (departure), and T (taxi) plus RI (runway incursions involving a vehicle). The geometry of each category is listed as: cr (crossing), tc (tail chase), and ho (head on) [4].The collision simulation presents the crossing incursion geometry; refer to Chapter 3.3.2.1 and Chapter 4.2.

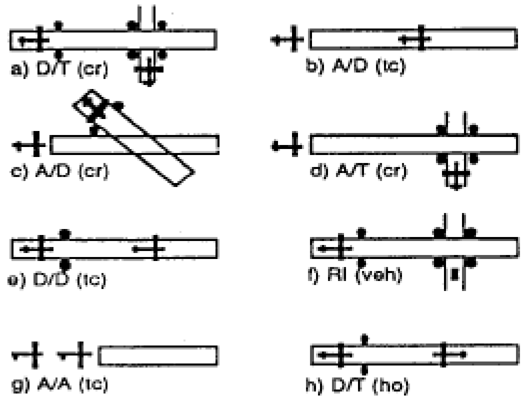


Figure 2-8 Airport incursion categories by movement process and incursion geometry [4]

2.5.4 Incursion Spacing Definition

During the motion, the required longitudinal separation depends on several elements relative to the cooperative vehicle movement. Figure 2-9 illustrates that in the calculation of the required longitudinal spacing, the following parameters need to be considered:

- Sd (detection distance): The distance covered by the other aircraft during the total time required for the pilot, controller A-SMGCS to react;
- Sv (braking distance): The distance needed for an aircraft to stop;
- Ss (safety margin): The minimum distance to be maintained between two aircraft at all times excluding jet blast effects;
- Lj (jet blast margin): The the distance behind the aircraft that must be kept clear to avoid jet blast effects;
- La (aircraft length);

St (minimum longitudinal spacing) = Sd + Sv + Ss + Lj + La (2-1)

Sp = Lj + La (2-2)

Based on A-SMGCS collision alerting principle, the spacing of St, which is considered in FAA runway safety report [1] as the minimum longitudinal spacing between two aircraft during the "tail chasing geometry" airport movements, should be kept to avoid surface collision (Equation 2-1); and spacing of Sp is the distance keeping one aircraft from jet blast affection of the aircraft operating behind it in the same direction (Equation 2-2).

The project applies this spacing definition into simulation qualitatively; refers to Chapter 3.3.6.2 and Chapter 4.2.

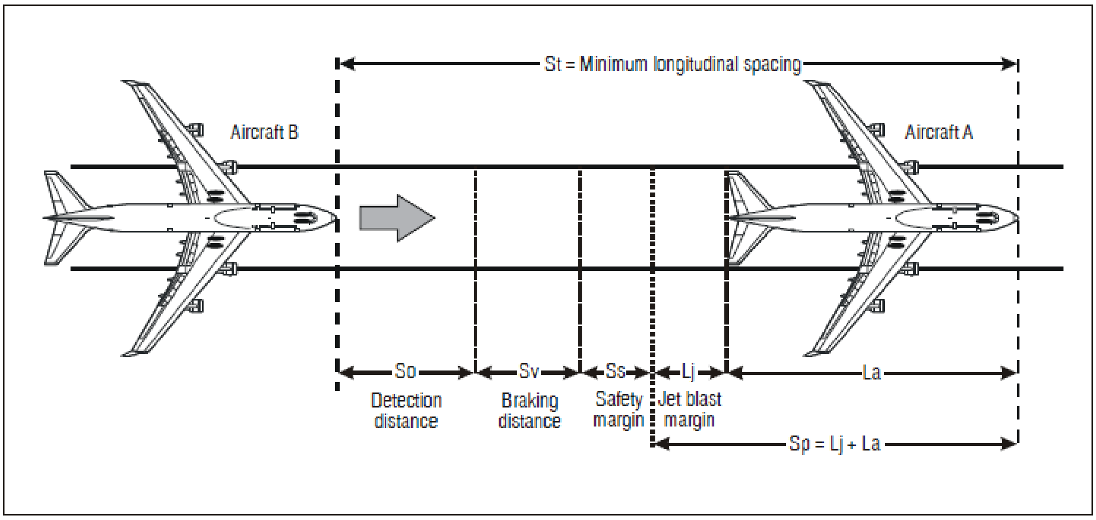


Figure 2-9 Longitudinal spacing parameters [2]

Being applied over the whole airport surface, including the runways and taxiways, the A-SMGCS is introduced to improve the vehicle moving management, benefited both by the ground controller and pilots/vehicle drivers. The system architecture and simulation is according to the definition of the incursion.

2.5.5 Incursion Severity

According to the different principle for incident impact evaluation, there are different ways to guarantee the airport safety issues into categories. Regarding the indent generator, the FAA Runway Safety Report (2004) [1] divides the incursions into three types: operational errors/deviations, pilot deviations, and vehicle/pedestrian deviations. In case of taking the incident severity level into account, there are four sorts of incidents with significant level from lowest to highest, as shown in Figure 2-10.

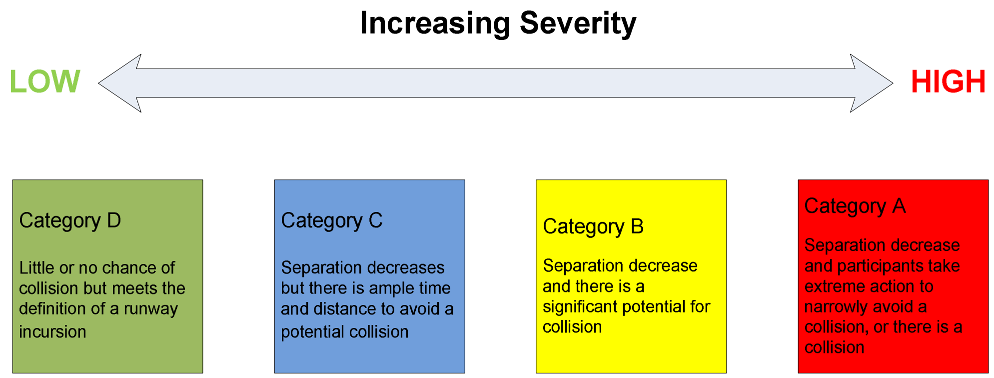


Figure 2-10 Airport incursion categories by increasing severity [1]

This incursion category is taken into consideration when defining incident danger level in the system implementation performed in this project.

In the simulation, the airport surface moving targets and alerts are assigned colors according to the severity levels defined in Figure 2-10; refer to Chapter 3.3.5, Chapter 3.3.6.2 and Chapter 4.2.

2.6 System Functions Configurations and Architectures

2.6.1 System Philosophy and Benefits

The concept of A-SMGCS includes comprehensive surveillance elements, data processing unit, wireless data communication, and HMI related to them.

The system is able to locate the aircraft and vehicles within the area of interest and distinguish the aircraft's unique ID. The data processing unit is integrated in a set of rules which generates the collision alerts when it goes against with the surveillance data. Signals between ground and onboard are delivered by data communication.

The traffic information and corresponding alerts are able to be viewed on AMM in ground stations and cockpit. The HMI provides operators with an interface to select ideal surface paths and hold points as clearance plan setting.

The benefits of A-SMGCS play a key role in motivation on A-SMGCS developments. A-SMGCS contribute progresses for airport operations in terms of safety and efficiency. The airport operator and passengers benefit from a reduction in diversions and cancellations. There may also be advantages relating to human factors, and the reduction of manual navigation overload.

The comparisons between traditional SMGCS and A-SMGCS are illustrated in Appendix A.

2.6.2 System Function Configuration

A-SMGCS provids routing, guidance, surveillance and controlling for airport surface aircraft and vehicles, in order to maintain the declared surface movement rate under all local weather conditions with the required level of safety maintained.

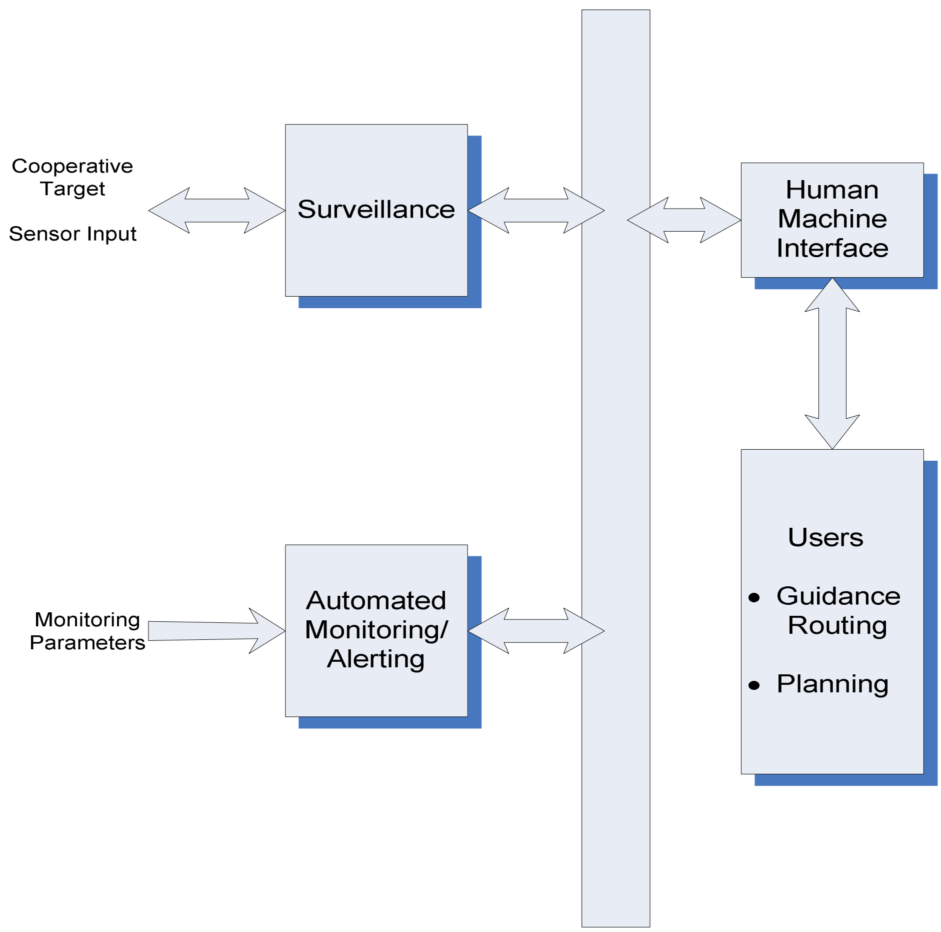


Figure 2-11 A-SMGCS function [8]

A-SMGCS uses the comprehensive available surveillance data to monitor the traffic situation in the area of interest, meanwhile a deviation contract software is hosted in monitoring parameter management unit; the input of surveillance information going against the set of rules will enable the system to alert the user to hazardous situations. See Figure 2-11for the general function diagram.

As shown in Figure 2-12 the surveillance elements include the cooperative part and non-cooperative part. The cooperative surveillance mainly supported by ADS-B, and the radar techniques provide the non-cooperative types.

The data fusion unit processes the surveillance inputs to an acceptable format and then sends them to proper HMI. The surveillance information, covering vehicle position updating, the airport surface layout and paths labels, can be viewed by the ground controllers and pilots.

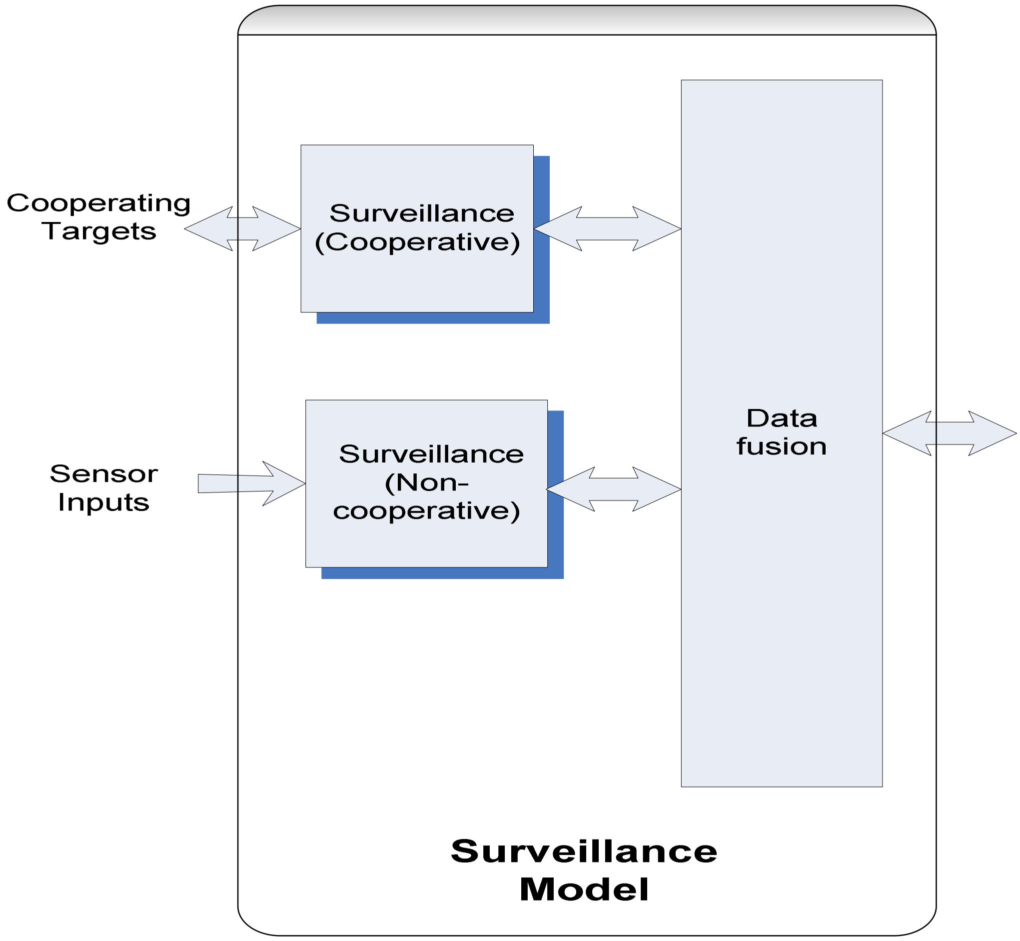


Figure 2-12 Surveillance function [8]

2.6.3 System Function Description

Considering the A-SMGCS concept, it requires the surveillance data inputs of all aircraft and vehicles in the airport movement areas, and provides operators with the AMM, periodically updating a synthetic image reflecting the current traffic conditions. The airport traffic control data includes routing planning and proximity alerting, enabling vehicle guidance and separation indications.

According to the ICAO A-SMGCS manual [2], an A-SMGCS should be capable of operating at a specified movement rate in visibility conditions down to the aerodrome visibility operational level (AVOL). When visibility conditions are reduced to below AVOL, an A-SMGCS should provide for a reduction of surface movements of aircraft and vehicles to a level acceptable for the new situation.

By using the technologies shown in Table 2-2 (chapter 2.4), the pilots' operations in the airport area can be improved by information in terms of:

- The ownship positions relative to runway/taxiway edges;
- Which runway or taxiway they are currently on and planning to have route to;
- The potential proximity and intersection from other targets, which could be identified as intruders;
- The intruder ID;
- The visual alerts about the possible collision risks.

2.6.4 System Architectures

2.6.4.1 Avionics system architecture on the ground

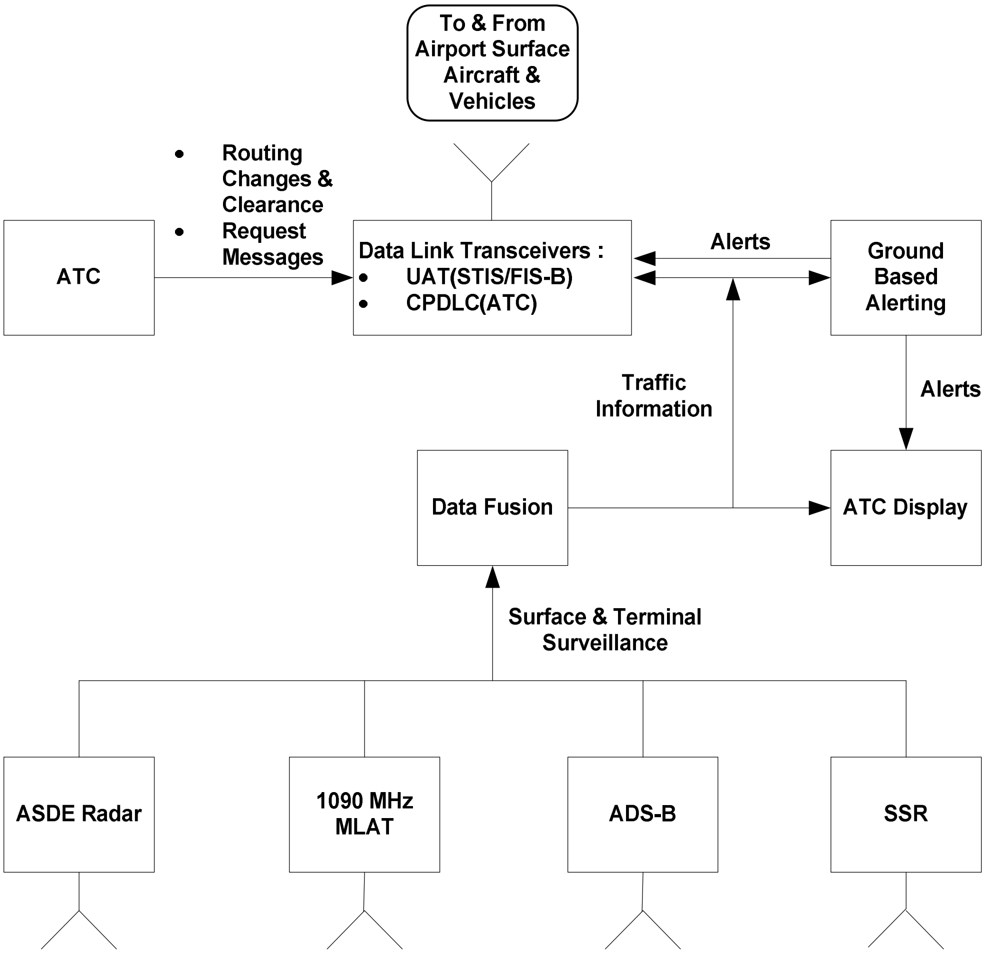


Figure 2-13 Avionics system architecture on the ground [10]

As shown in Figure 2-13 the ground infrastructure, relative to the A-SMGCS, includes:

- The surface surveillance;
- The data processing module;
- The ground-based alerting generator;
- The AMM display unit;

- The routing plan HMI;
- The ground-onboard data communication.

The surface surveillance infrastructure provides the surface traffic information as input to the data processing module. The ground controllers are supposed to obtain airport surface and terminal traffic information through the ASDE radar, 1090 MHz multi-lateration, ADS-B, and SSR.

- The ASDE-3 is Ku band primary radar used for the aircraft and vehicles moving on runways and taxiways that are in direct line of site to radar; therefore the non-movement areas including grass, apron and ramp zones are automatically filtered out. In addition, the ASDE-3 provides enhanced surface movement surveillance in low visibility conditions, contributing to a rise of safety and reduction of collision risks.
- The 1090 MHz multi-lateration (MLAT) is broadly utilized in the fields of civil and military surveillance. By measuring the time difference between emissions of a signal from three or more receiver sites, the multi-lateration accurately locates an aircraft, vehicle or stationary emitter. One of the significant applications of the MLAT is the airport surface surveillance as an essential part of the A-SMGCS system. The MLAT supports ground conflict detection by providing frequent updates of equipped aircraft and vehicles, which enables the monitoring of aircraft and vehicles regarding runway incursions and taxiway operations in low visibility conditions.
- Under ADS-B, a vehicle periodically broadcasts its own state vector and other position information, without extra requirements of the confirmation of other aircraft or ground station receiving the signals, or the expectation of a reply. ADS-B is automatic in the sense that it requires no human actions to transmit the information. It is dependent surveillance in the sense that the surveillance information is obtained depending on the suitable navigation and broadcast capability in the source aircraft.[5] International aviation

standards for the individual ADS-B data link technologies have been standardized by the International Civil Aviation Organization. [9]

- For SSR usually, but not necessarily, a ground station transmits a coded signal containing the requested information and gets a reply from the onboard SSR transponder. The transponder is a radio receiver and transmitter which receives on one frequency (1090 MHz) and transmits on another (1030 MHz). A ground SSR continuously transmits interrogation as its antenna rotates, and the transponder onboard monitors the SSR interrogation signal and sends back a reply to provide aircraft information. On ground, the aircraft is then displayed as a tagged icon on the controller's radar screen placed in the calculated bearing and range.

As a subset of the surveillance server, the data fusion unit takes surveillance data as input and digitalizes them. Based on the surveillance data the surface moving targets information could be determined and output to three resources: ground controller interface, ground alerting algorithm module, and ground-onboard data-link.

To generate the relative alerting on ground for both the ground controllers and onboard operators, the ground-based alerting system, resident on the surveillance server, maintains the updated surveillance data in the database, and then analyzes the traffic location and movement to identify potential hazards. The alerting system also generates hold bars which could be viewed on ground ATC display and transmitted to cockpit display.

The ground HMI is primarily used to support ATC, including the ATC. The ground controllers are able to view the surface traffic information on the ATC display, in terms of target positions and movement, potential collision alerting, and suggested hold bars. Based on the probable awareness of the interested area traffic, the ground stations are correspondingly capable of providing the following control operation to aircraft and surface vehicles:

- Airport clearance: designate the taxiway/runway and related hold points by selecting the parameters listed in HMI. Subsequently the designated routing plan will be sent to the equipped aircraft and surface vehicles through FIS/STIS-B.

- Routing alternation: once a conflict has been detected, the A-SMGCS enables either provision of automatic path validation or requests about the most suitable solutions from controllers.

- Request message: the ground controllers are allowed to send message to request reports from onboard operation personnel.

2.6.4.2 Avionics system architecture onboard

As illustrated in Figure 2-14 the avionics system installed on aircraft or surface vehicles is supposed to consist of the following units, to work as the onboard part of the A-SMGCS system:

- The data link transceiver;

- The LAAS receiver;

- The ADS-B transceiver;

- The onboard alerting generator;

- The onboard AMM display;

- The aural alerting units.

From the FIS/STIS-B receiver, the onboard A-SMGCS avionics system obtains regular surface traffic information, ground-generated alerting and hold bar indications. The received data is delivered as one of the inputs to the cockpit AMM and onboard alerting generator. Via CPDLC, the pilots and vehicle drivers are enabled the capacities to change messages with ATC, in terms of the following aspects:

- To response to the ground messages;
- To request clearances and information;
- To report the ownship information;
- To declare/rescind an emergency;
- A ‘free text’ capability.

Other two traffic information inputs come respectively from LAAS receiver and ADS-B transceiver. Obtaining the differential GPS navigation data and the Inertial Navigation System (INS) data, the former provides aircraft and ground vehicles with the ownship updated position; the latter enables the onboard A-SMGCS to receive the ADS-B signals from other surface equipped targets, and to send the ownship GPS information to the ground stations and other aircraft and vehicles within the operation range.

The onboard alerting unit takes data link data and ADS-B information as sources for traffic information, based on which it provides algorithm for proximity judgement and corresponding alert generation. The early conditions for runway incursions allow the vehicle drivers/pilots sufficient time to avoid runway conflicts and collisions when an alert is issued.

The traffic information and necessary indications displayed for pilots/vehicle drivers can be viewed on an AMM integrated into a unit with ND or installed independently. Besides the visual alerting, the system provides aural indications to operation personnel as well, as a provision of awareness for AMM.

One of the installation design for AMM in cockpit represented in Appendix D (Chapter 2.3**,** Figure 1), as part of the cockpit layout design.

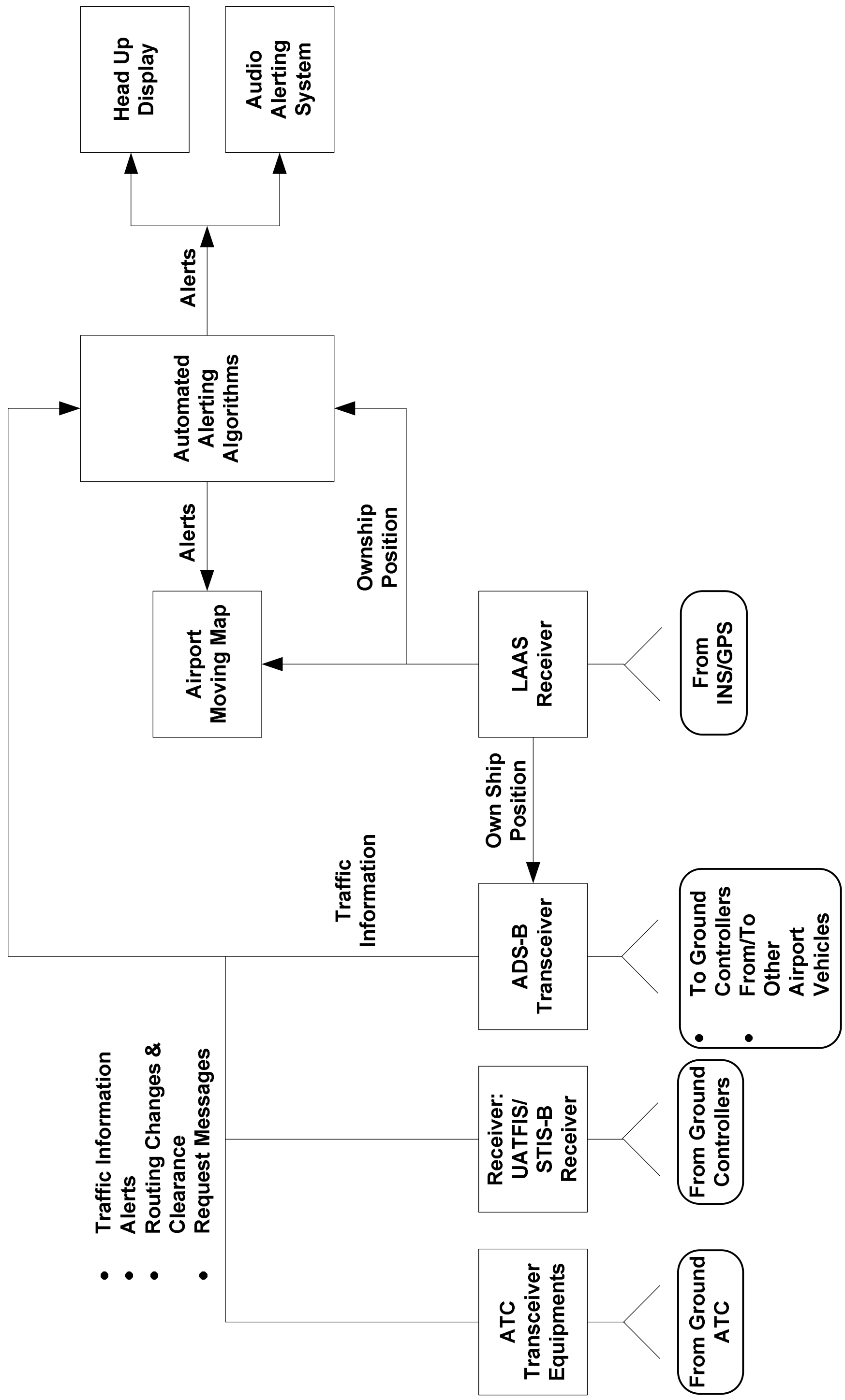


Figure 2-14 Avionics system architecture onboard [10]

2.6.5 Communication in A-SMGCS

In A-SMGCS, the communication path between the ground-based transceiver and the aircraft-based transceiver is mainly authorized as the data link system of FIS/STIS-B and CPDLC.

Via the FIS/STIS-B, the communication operates in the L band and updates the surface traffic information once per second. The FIS/STIS-B transmits data include regular surface traffic information, ground-generated alerting and hold bar indications.

The CPDLC provides the digital ATC information transmission. The sequence of CPDLC message between a controller and pilot or a vehicle driver is termed a 'dialogue', within which there could be several messages, usually closed by means of appropriate messages such as acknowledgement or acceptance. Closure of the dialogue does not necessarily means the termination of the link, since the CPDLC communication allows more than one dialogues delivering at the same time.

The messages transmitted though the data link include:

- Traffic Information;
- Alerts;
- Routing Changes & Clearance;
- Request Messages.

As commonly utilized in traditional SMGCS, the radio communication exists in A-SMGCS as a supplement to data link. The information delivered though radio communication includes:

- ATC messages;
- Pilot/ vehicle driver reports and requests.

3 Simulation Implementation

3.1 Principles and Tasks

This project deals with a basic A-SMGCS simulation model and to implement an AMM display for surface traffic viewing in ground station and cockpit. Main system functions required by Advanced Surface Movement Guidance and Control System (A-SMGCS) Manual [2] will be presented in the simulation results.

The ICAO A-SMGCS manual [2] defines four main function elements as: surveillance, routing, guidance, and controlling.

The surveillance functions generally include the provision of target positions and the identifications of the targets. According to this, the simulation supports the moving target position updating, and the corresponding labels showing the aircraft tail number.

The routing performance includes the indication for the moving routes and the routes shifting. In the simulation implementation there are airport path and relative hold points labels to show the surface layout, but for the time limitation of this project, the indication parts need to be finished in the future work.

In guidance and control function definitions, the A-SMGCS should support surface collision alerting and runway occupation. This performance will be implemented in the simulation; the alerts are designed into two different severity levels.

Based on the above-mentioned principles, the system model will be designed to finish the following tasks:

- Target movement data acquisition;
- Data processing;
- Target incursion calculation and alert generation.

Regarding the display image processing, related programming includes:

- Image pre-treatment;
- Image restoration;
- Image filtering;
- Image enhancement.

The GUI design contributes a HMI for AMM model operation.

The simulation contributes an integrated environment to demonstrate performance of A-SMGCS basic functions, with HMI as inputs and AMM display as outputs.

This model is expandable for:

- Implementation of emergent routings alternations;
- Improved HMI.

The design tasks are set to comply with the ICAO manual [2].

3.2 The Airport Selection

The airport selected in this project for the implementation of AMM display, as shown in Figure 3-1, is the Cranfield University airport. This airport belongs to a class G airspace located outside the village of Cranfield, 7 NM (13 km; 8.1 mi) southwest of Bedford in Bedfordshire, England, and was originally a World War II aerodrome.

Cranfield airport is capable to operate flights for public transport of passengers or for flight school as authorized by the licenses. Besides, the airport facilities are utilized by general aviation, small business aircraft and private jets. Additionally, the airport extensively supports fixed-wing and helicopter flight training.

Figure 3-1 Layout of Cranfield airport [10]

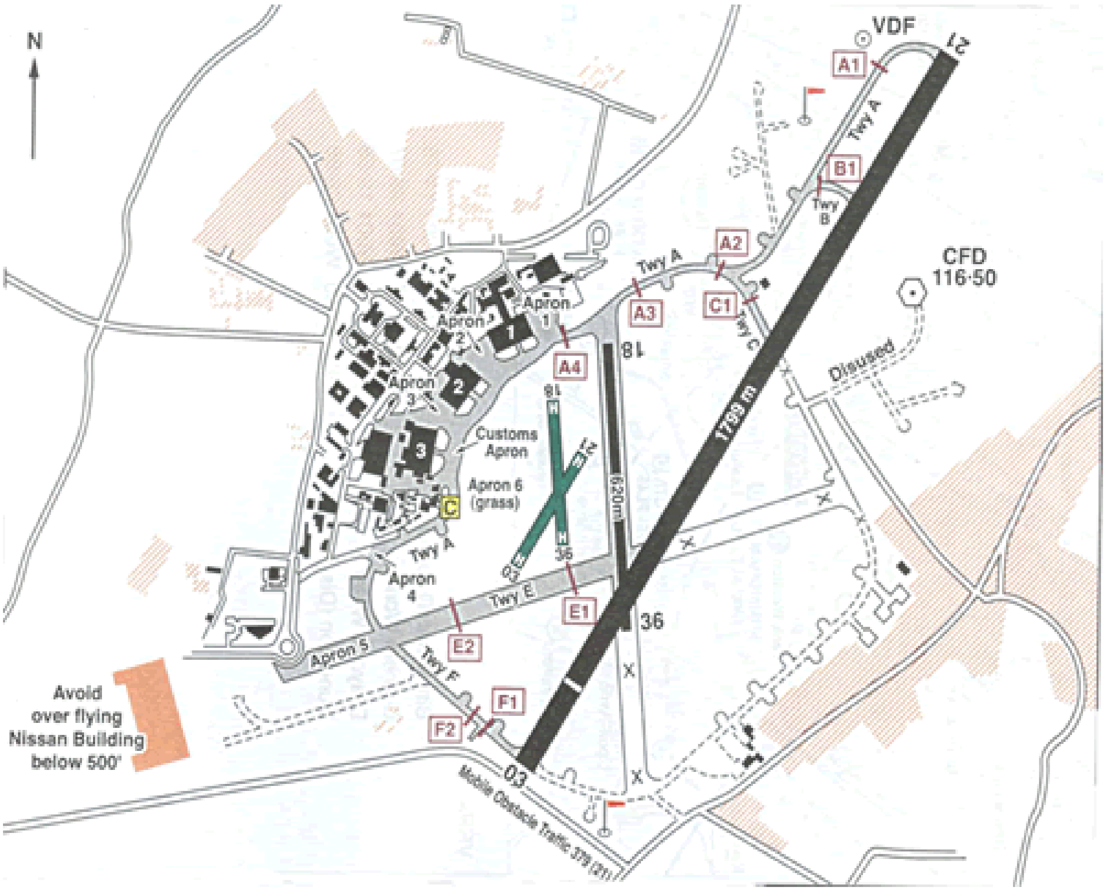


Figure 3-2 Cranfield airport information for guidance [10]

There are 2 runways and 6 taxiways (Twy A to Twy F) on Cranfield airport surface. Figure 3-2 illustrates the guidance information about the surface, and the data listed in Table 3-1 is about the Cranfield runway parameters, including the direction and length of the runways, and the runway paving material.

Table 3-1 Cranfield airport runway information [11]

Direction	Length		Surface
	m	ft	
03/21	1,799	5.902	Asphalt
18/36	620	2.033	Asphalt

As demonstrated in chapter 2.5.3, the incident geometries simulated in this project include tail chase, head on, and crossing. Combining with the consideration of movement conditions including arrival, departure, taxi, and runway incursions involving a vehicle, the geometries are implemented in different speed and areas.

The airport is selected to be processed into a bottom layer as the simulation scenario background. The moving targets, standing for the operating aircraft or vehicles on surface, will be designed to have updating positions and simulated the collision conditions.

Selections of airport need sevral conditions relavant to the airport capabilities and the possiblities of the application in simulation.

The Cranfied airport is selected for this simulation because it has:

- Capability of supporting the airport surface movements, covering the normal path tracks and incursion conditions;
- Maintainance of sufficient level of functionality to demonstrate the system;
- The surface scenarios allowing for a simple and clear simulation;
- The layout typicalness for a easy understanding.

3.3 Simulation

3.3.1 Simulation Flowchart

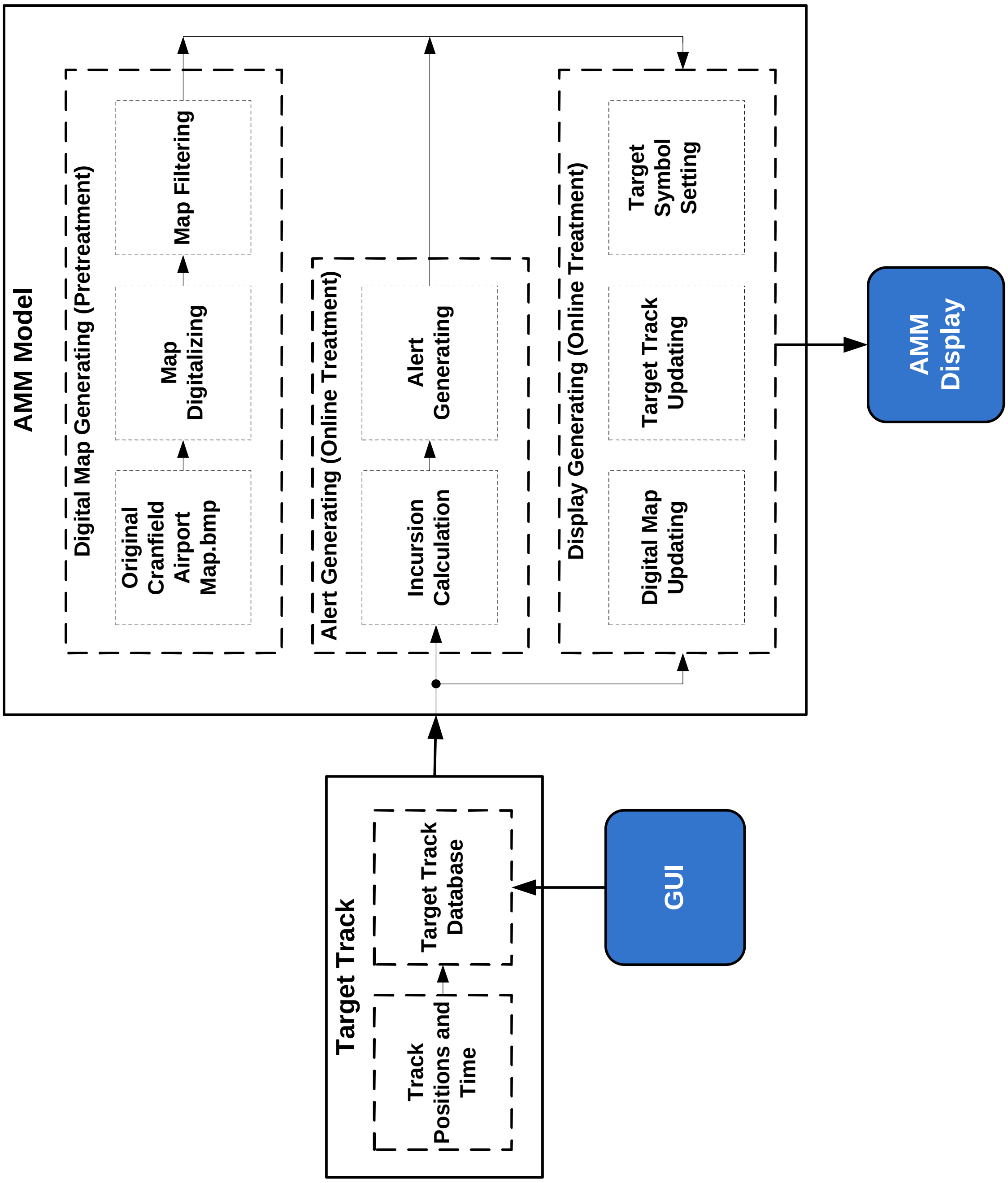


Figure 3-3 Simulation flowchart

In Figure 3-3, the flowchart describes the comprehensive architecture of the simulation and each component in it.

The Following parts were implemented in the Matlab program:

- Target track (position and time) setting;
- Track database building;
- Digital map generating and filtering;
- Intruder position updating and rotating;
- Map updating and rotating;
- Alert scenario designing.

A Simulink model implements the following computations:

- Target track data processing;
- Incursion condition calculation;
- AMM display.

The GUI unit provides an interface window for airport surface clearance setting. In this window, the user is enabled to set routings. The GUI commands are sent to target track database as input.

The HMI in the simulation consists of the display and clearance setting window, as highlighted in Figure 3-3.

3.3.2 Target Track

3.3.2.1 Track Path Layout

The moving targets, with the symbol of aircraft, in this simulation include one ownship and one intruder. The tracking paths are Taxiway A, B, C, E, F. For each taxiway the aircraft stopping point can be preset through the GUI, at the end of taxiway of the runway edge, or any hold points on the taxiway. There is one hold point on the runway. The track paths are according to the real Cranfield airport layout. The hold points on each taxiway are listed in Table 3-2. The routing layout selection is based on the crossing collision geometry, as mentioned in Chapter 2.5.3. Refer Figure 3-2 for track layout corresponding to Table 3-2.

Based on this surface configuration, the target tracks in this simulation cover:

- Ownship and intruder moving on taxiways;
- Ownship on runway, and intruder moving across the runway.

Table 3-2 Taxiway Hold Point Configuration

Taxiway	Hold Point
A	A4
	A3
	A2
	A1
	Runway Edge
B	B1
	A2
	A3
	Apron1
C	C1
	A2
	A3
	Apron1
A/C	A3
	A2
	C1
	TWA E

Taxiway	Hold Point
A	RWA Edge
	Hold Short Lights
	RWA End

3.3.2.2 Target Track Database Design

As the inputs for the target track on taxiways, the positions of geodetic latitude, longitude corresponding to each step are calculated from the real map.

The initial target track data is stored as a cell array data type, which supports the ability to store arrays of mixed sizes and to store selected data together in a single entity: this enables index processing in the programming control loop. This type of variable has been chosen for these reasons:

- It supports the access and control on all or parts of the data collectively;
- Functions in program can directly access an array, and arrays are able to be passed to and from M-file functions;
- The value of any fields is able to be displayed, and most MATLAB operation on the contents of an array could be performed;
- Compared with structure data in this case, the cell array requires less software memory allocation.

Figure 3-4 presents the main program flowchart for target track database establishment and calling.

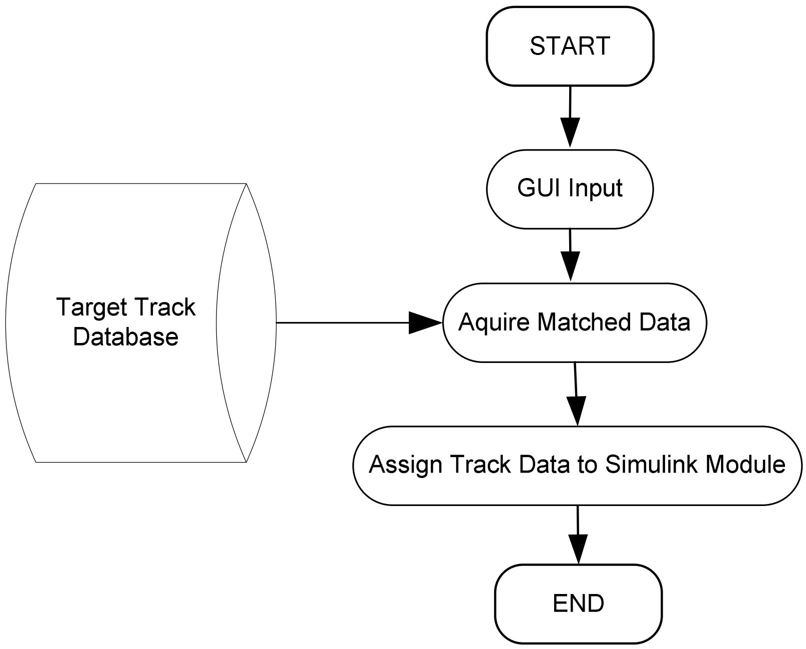


Figure 3-4 Main program flowchart for target track database establishment

The original data of the target positions are expressed in geodetic geographic coordinate system Latitude, Longitude and Altitude (LLA). This is firstly converted to Earth-centred Earth-fixed (ECEF) and then to the North-East-Down (NED).

In this way the data finally displayed on the terminal map as simulation results are referred to the local horizontal plane. This conversion has been performed for two reasons:

- To make the position coordinates understandable for the operational persons;
- To help the incursion calculation.

The ownship and intruder track database, as the GPS surveillance signals, has interface with GUI and AMM block.

3.3.2.3 Intruder Track Design

On the terminal display, the position of target is shown fixed in the centre of the screen, subsequently the moving and rotating of intruder are relative to the ownship. Figure 3-5 and Figure 3-6 illustrate the algorithms used to calculate the intruder positions and rotations relative to the ownship.

In the program the following variables are defined:

- [Xac Yac]: the ownship position vector;
- [IntrX IntrY]: the intruder position vector;
- Ownship_Heading: the rotation angle of the ownship.

The position vectors are calculated in LLA system with the unit of degree. The Ownship_Heading is calculated in the unit of degree.

Explanations for the parameters in Figure 3-6:

- [IntrX IntrY] is the intruder position vector relative to the ownship position vector, as demonstrated in Figure 3-5
- IntrP: [IntrX IntrY] after rotation;
- Θ: Θ =- Ownship_Heading.

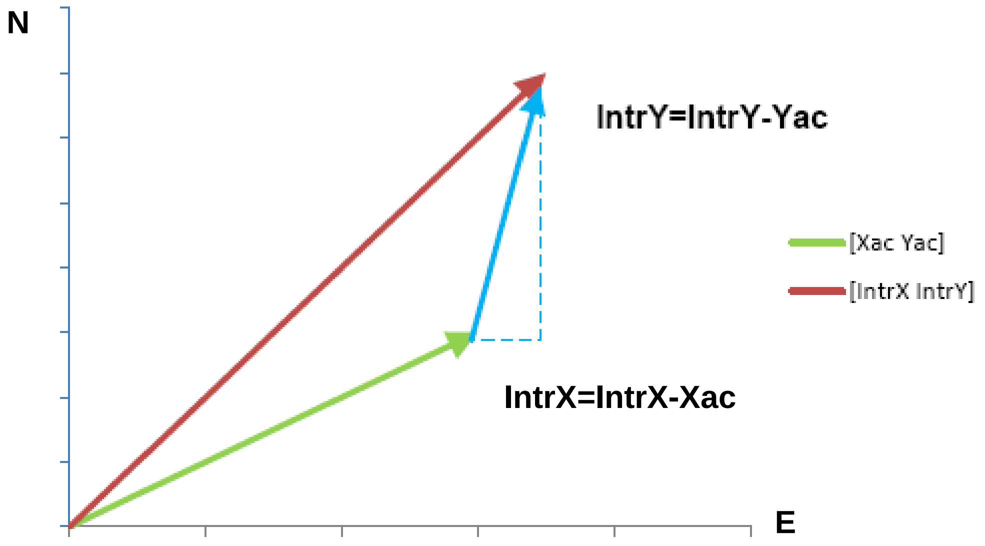


Figure 3-5 Intruder relative position calculation

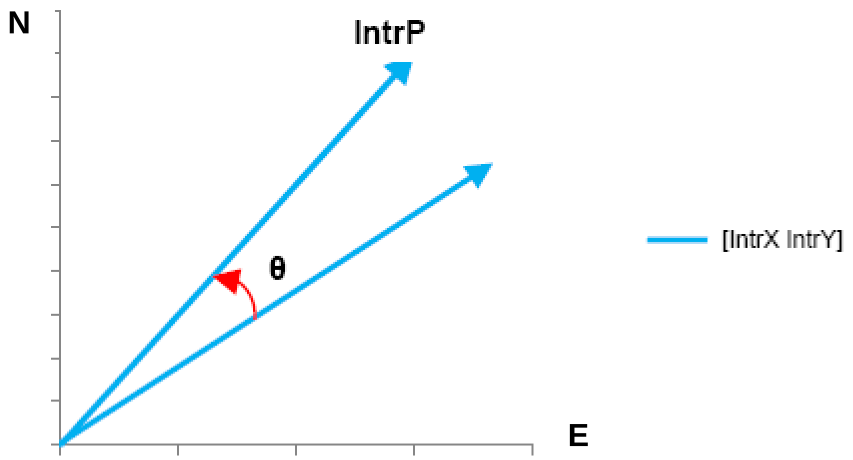


Figure 3-6 Intruder relative rotation calculation

Taking the original intruder positions as inputs, the intruder heading calculation is implemented in Simulink. Figure 3-7 illustrates the algorithm for intruder heading calculation.

$$\mathbf{Intrder\_Heading} = \mathbf{arctan}\frac{\mathbf{IntrY_2 - IntrY_1}}{\mathbf{IntrX_2 - IntrX_1}} \quad \textbf{(3-1)}$$

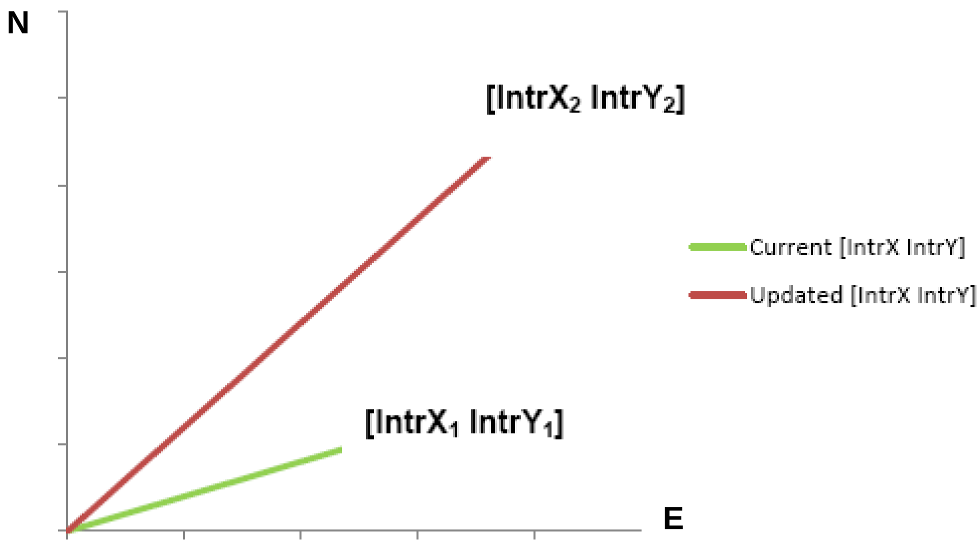


Figure 3-7 Intruder heading calculation

The main program flowchart for intruder movement updating is demonstrated in Figure 3-8.

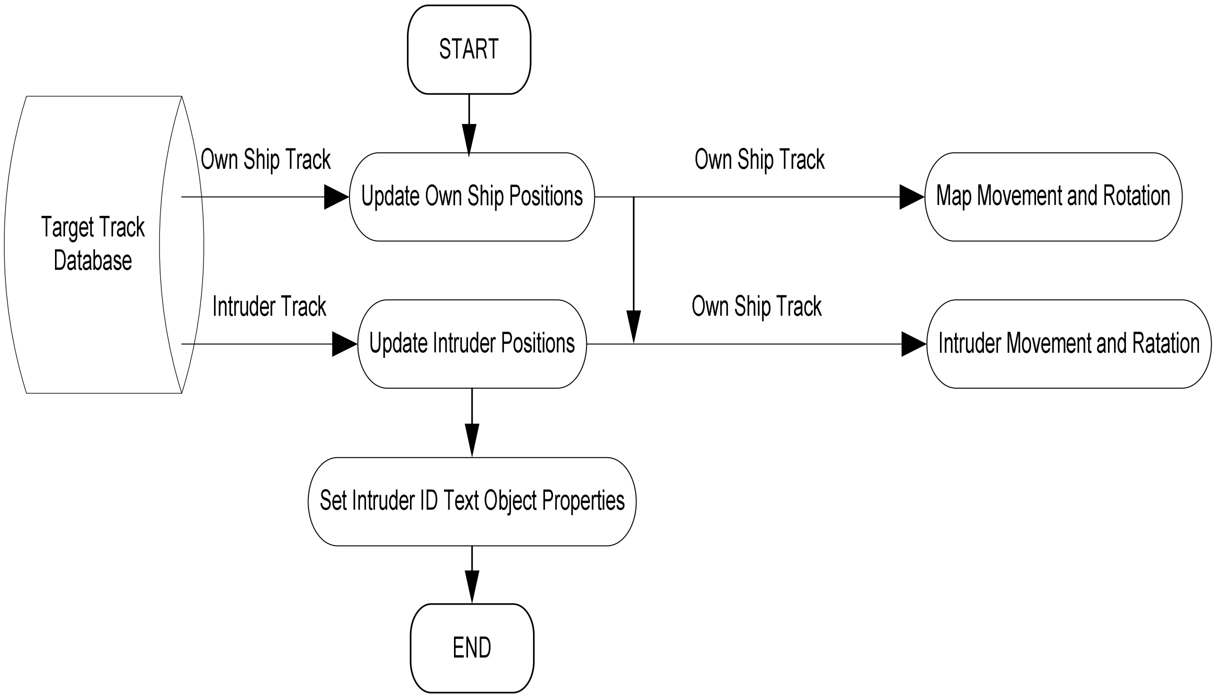


Figure 3-8 Main program flowchart for intruder movement updating

3.3.3 Image Processing

3.3.3.1 Image Pre-treatment

The digital airport map is first generated from the bmp format image into a database by the function “imread”. This phase builds a RGB image, also referred to as a true color image, stored as an *m*-by-*n*-by-3 data array that defines Red, Green, and Blue (RGB) color components for each individual pixel, as shown in Figure 3-9.

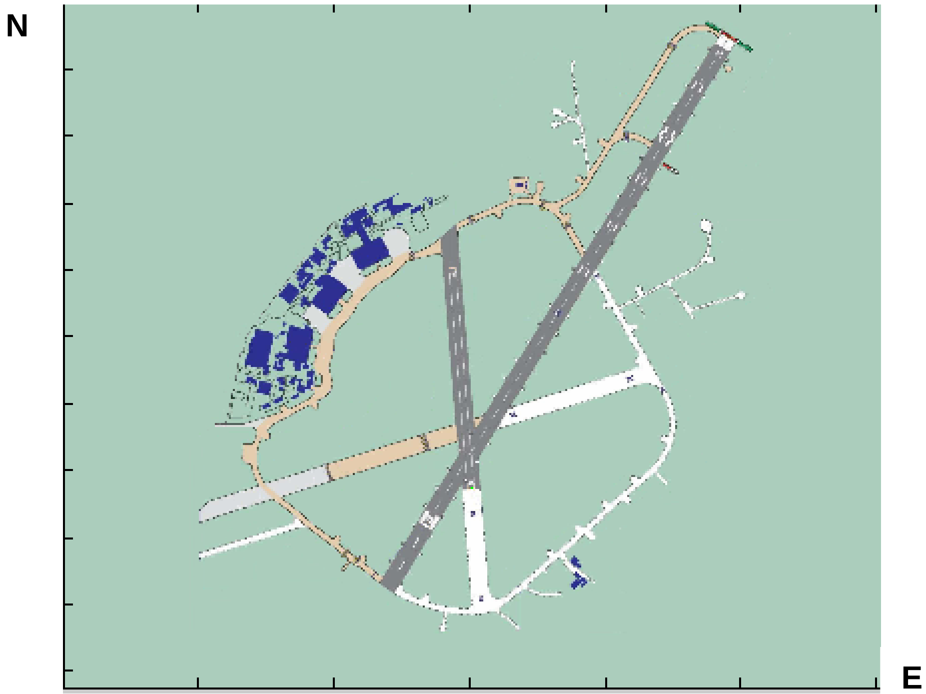


Figure 3-9 Digital map in RGB

3.3.3.2 Image Filtering

The conduction of image filtering is based on the the requirement of avoiding MATLAB software memory overload. By obtaining an indexed image from the RGB image, the image filter produces a reduction of the memory allocated for the image logging, with maintaining the basic original airport layout.

In this phase, the color difference is taken as the filtering principle. The comprehensive filtering algorithm are roughly descripted as following:

- To select a point from a unique color area, as a reference point;
- To measure the X-Y coordinate of the reference point, and the point RGB weights versus the coordinates can be detected in MATLAB subsequently, as the reference RGB weights;
- To select out the points having RGB weights same with the reference RGB weights;
- To set all of the selected points as one color layer;
- To repeat the above steps for each color area;
- To composite the layers into one image.

The displayed map presents the basic layout of the original one, but with a reduced software memory allocation and a speed-up model running.

Figure 3-10 shows a result illustrating the AMM image processed by the above precedures.

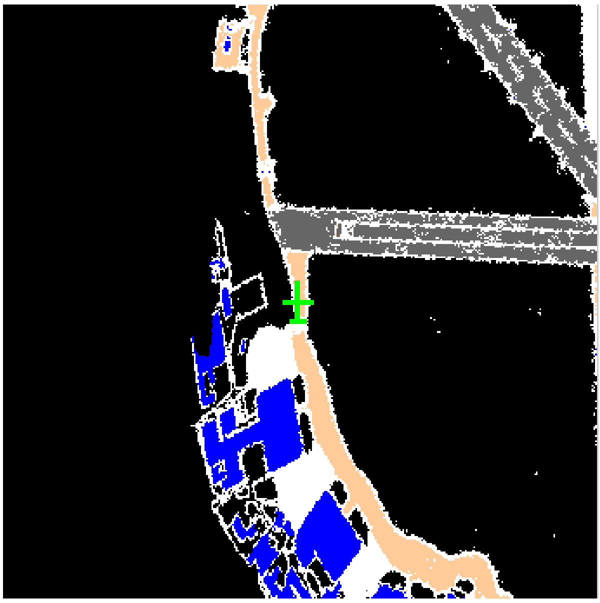


Figure 3-10 AMM without image enhancement

3.3.3.3 Image Enhancement

It is apparently shown from Figure 3-10 that the imaging efficacy is not ideal due to the elements as:

- Noisy points;
- Information which is not significant for surface traffic management is displayed on AMM.

To perform an image enhancement, the main approach is to refine a filtering by the following steps:

- To select a reference point from a unique color area, only for the areas contributing useful surface information;
- To measure the X-Y coordinate of the reference point, and the point RGB weights versus the coordinates can be detected in MATLAB subsequently, as the reference RGB weights;
- To locate the noisy points, in the same area, and calculate their RGB values;
- To estimate the RGB weight difference between the noisy points and the reference point;
- To set intervals for the reference RGB weights;
- To select out the points having the RGB weights within the preset intervals;
- To set all of the selected points as one color layer;
- To repeat the above steps for each color area, only for the areas contributing useful surface information;
- To composite the layers into one image.

To get rid of the noisy points on the image, locating them to get the position coordinates of the points could find out the RGB color components for the points. Based on the calculation of the RGB weight differences between the noisy points and the filtering standard color, a probable spread value could be set to define a RGB reference interval. This algorithm contributes an optimized image filtering process.

For similar but not accurately the same color, separating them into different layers could allow a more complete and clear image.

Another small step to achieve a whole visual improvement is to adjust the digital image pixel RGB weight to the values contributing colors closer to the original map.

Therefore 5 layers, as listed in Appendix B, are separately defined and then composed into a completed map.

Additionally, the original map is processed into a simpler layout, with more significance and clearer information for users.

Figure 3-11 presents the main program flowchart for image filtering.

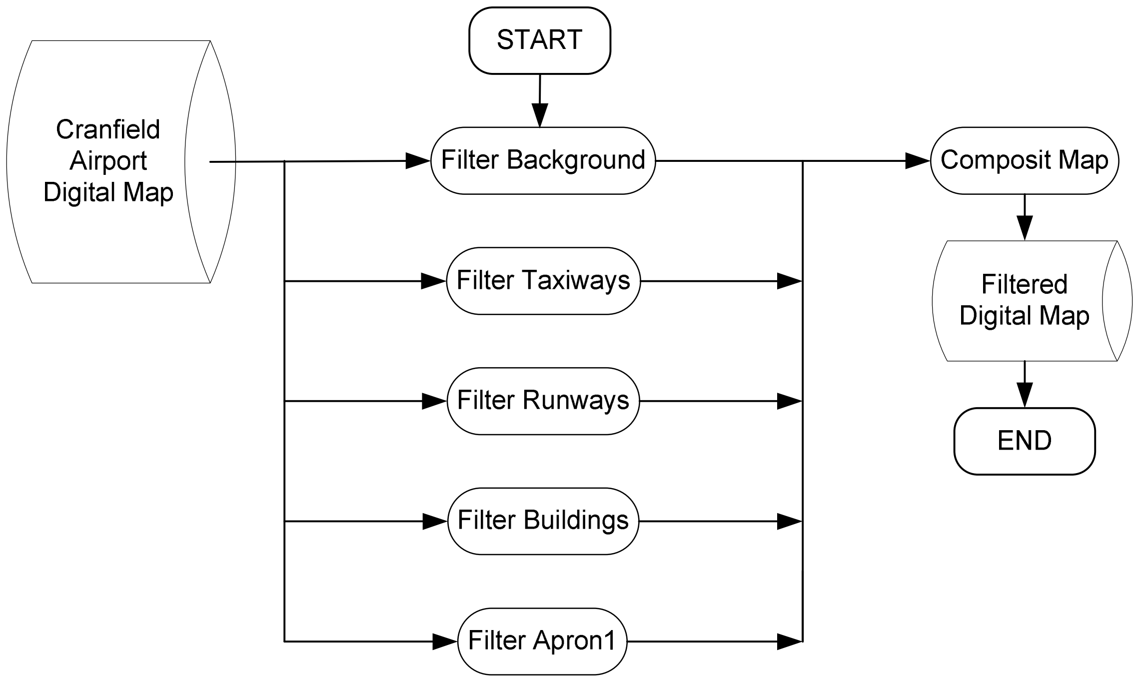


Figure 3-11 Main program flowchart for enhanced image filtering

The main codes for enhanced image filtering are listed in appendix C.

3.3.4 Map Movement and Rotation

To implement an AMM with the ownship fixed in the middle, the map moves and rotates relatively to the ownship.

Following the ownship track, the map updates its positions in an opposite way compared with the ownship movement. It subsequently presents the map movement from one position to the next, corresponding to the time points.

One point needing to be made clear is, the vehicle size and initial speed are constant and that no attempt has been made to model realistic acceleration and braking. This limitation needs to be solved out in the further work.

Figure 3-12 illustrates the program flowchart program flowchart for map display.

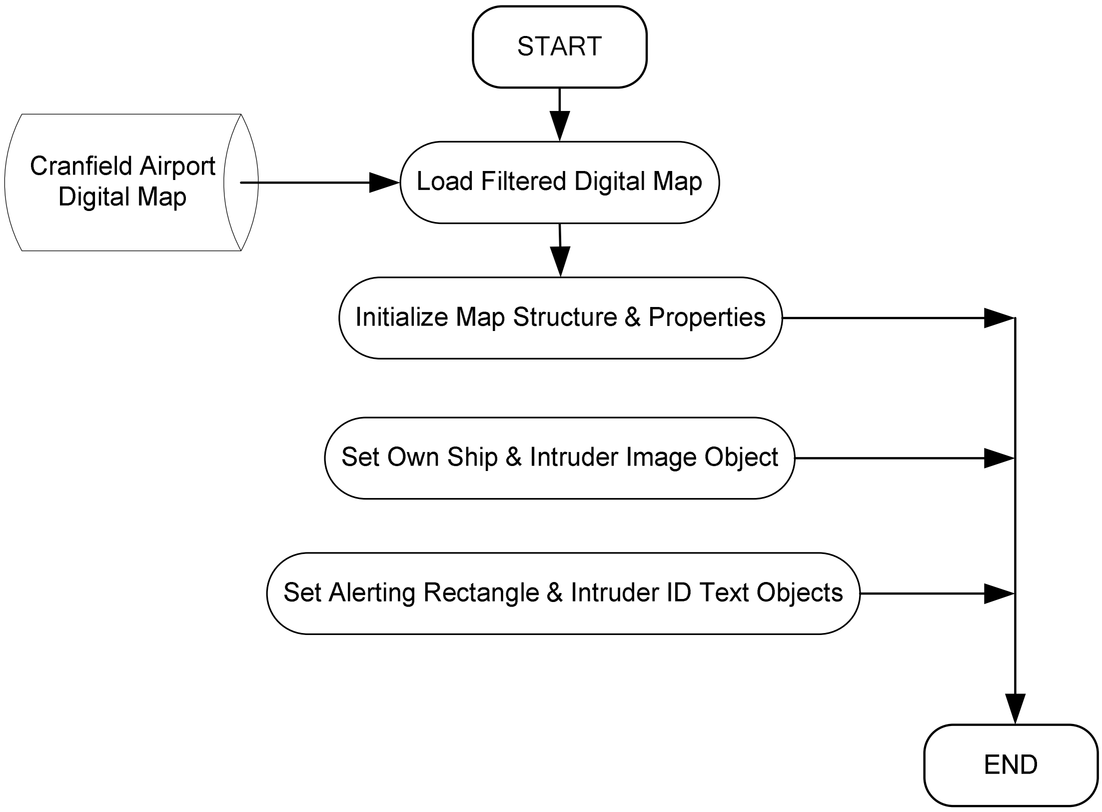


Figure 3-12 Main program flowchart for map display

3.3.5 Target Symbols and Scenarios

The ownship (shown in Figure 3-13) and the intruder (shown in Figure 3-14) have the same shape, which allows the target heading and rotating a clear display efficacy during movement. According to Figure 2-10, the color for the ownship is green and for intruder is blue. With collision condition alerts generated, the intruder color turns into red.

There is a safe separation symbol to indicate the distance needed to be maintained between the ownship and intruder, otherwise the traffic alternates into collision or potential collision condition. Additionally, the intruder ID is defined to move following the intruder track. When the safe separation between the ownship and intruder is lost, the intruder symbol, intruder ID and separation indication change their color from blue to red to present the alert.

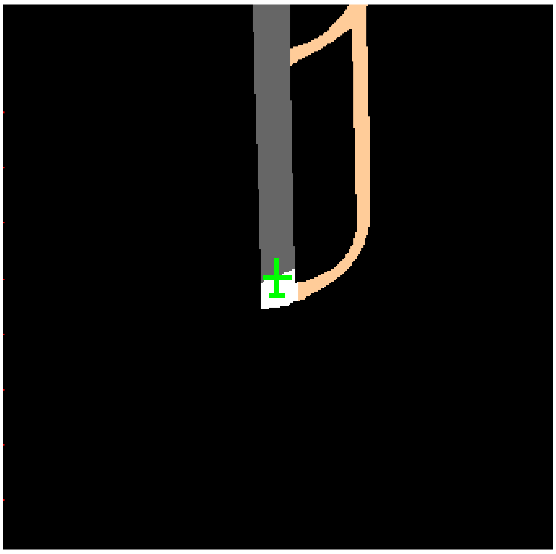


Figure 3-13 ownship symbol

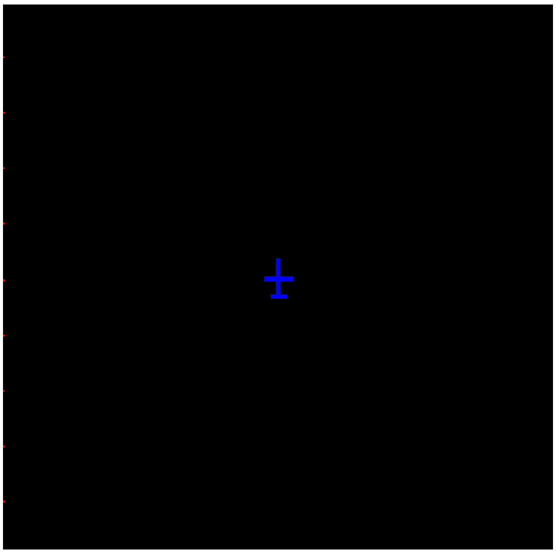


Figure 3-14 Intruder symbol

3.3.6 Incursion Alert Generating

3.3.6.1 Principle and Model

The incursion alert generating block is integrated in the AMM block. Based on the existing intruder positions relative to the ownship, the distance between the intruder and ownship is calculated as presented in Figure 3-5. To take the intruder relative position data as a 2 element vector for every time point, the NORM of the vector is calculated, obtaining an estimation about the distance scalar between the intruder and the ownship.

As formulated in Chapter 3.3.2.3, there are following vectors defined:

- [Xac Yac]: the ownship position vector;
- [IntrX IntrY]: the original intruder position vector.

$$\mathbf{Distance} = \sqrt{(\mathbf{IntrX} - \mathbf{Xac})^2 + (\mathbf{IntrY} - \mathbf{Yac})^2} \tag{3-2}$$

The distance is a scalar sent to be compared with a fixed value and the result determines if there is an incursion. Additionally, the distance value of next step is compared with the current one through a time delay loop, which allows the alert to be cancelled when collision condition disappears.

The fixed value are not set as a accurate parameter in this simulation, but estimated qualitatively. In the future work, this value needs to be fixed according to the target speed and size.

According to A-SMGCS requirements, this simulation displays the cooperative movement of two aircraft within 3 phases:

- Moving with safe separation;
- Generating collision possibilities;

Alert is indicated for the 2nd phase.

3.3.6.2 Alert Display

There are two types of detections designed in this simulation for unusual conditions happening on surface:

- Alerts design for target proximities on taxiways and runway;
- Runway occupation warning for the ownship.

The principle of the alert visualization (see from Figure 3-14) is to provide the user a compendious and distinct view about the potential collision condition, which leads to the following design decisions:

- The alert lines: there are two concentric circles surrounding the ownship; one of them with larger radius, called Category B alert (Figure 2-10), indicates the ownship crews that the intruder has passed the hold point behind it and there is only one hold point for the ownship to stop; and the other one with radius standing for St (Equation 2-1), called Category A alert (Figure 2-10), indicates an proximity emergency between the ownship and intruder, for which the ownship crews have to take actions to brake and try to stop the aircraft as quickly as possible;
- The alert lines visualisation: they are set invisible without collision risks; that intruder touching the safe spacing lines will trigger the circles to be visible; the A alert circle is in color red and the B alert circle is assigned the color yellow, which is according to the severity levels defined in Figure 2-10; when intruder moves apart from the ownship, the alert lines disappear corresponding to the distance shifting;
- The intruder color: the generation of potential collision makes the intruder color change to the same color with the alert circles; when the alerts disappear, the intruder color changes back to blue;

- When the ownship is moving onto the runway and before surpassing the runway short hold points, the runway occupation caused by intruder's insertion triggers a runway occupation warning. Shown in Figure 3-15.;
- The alert or warning trigger a movement pause for map and intrude.

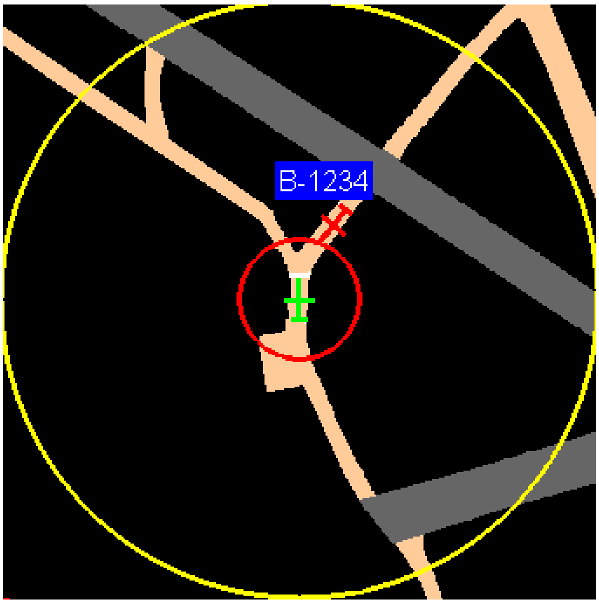


Figure 3-15 Alert image

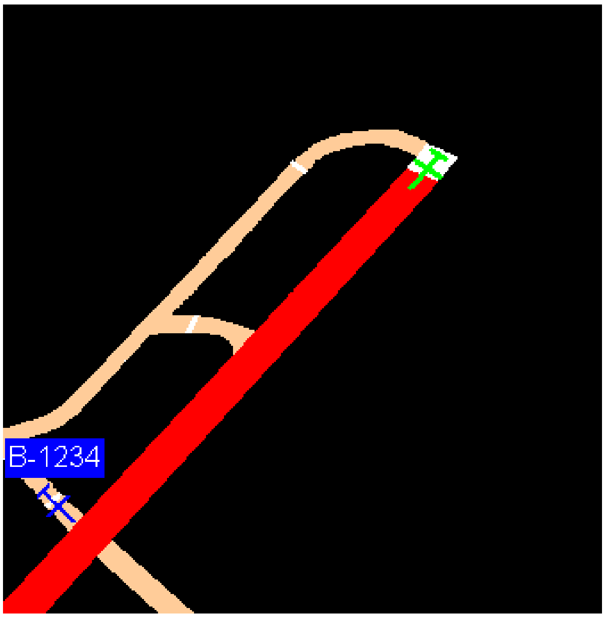


Figure 3-16 Runway Occupation Scenario

3.3.7 AMM Model

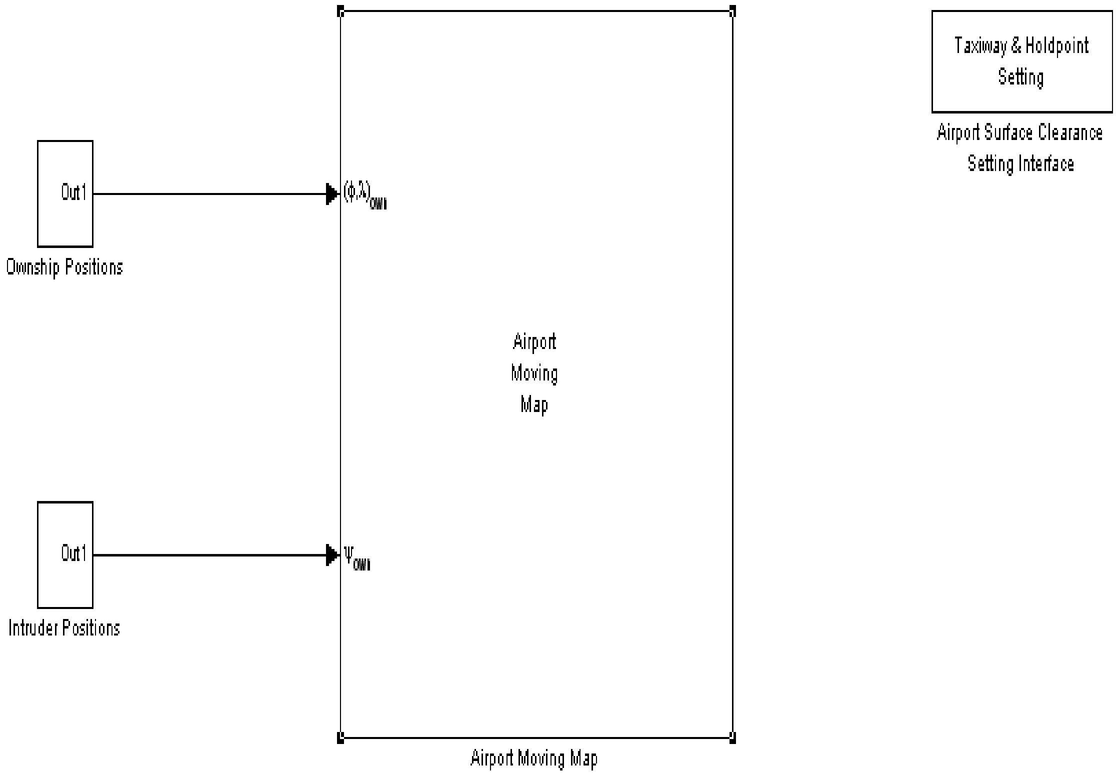


Figure 3-17 Main Simulink model layout

Figure 3-17 presents the main Simulink block for this implementation, with a GUI as user interface unit, target track providing surveillance data input, and AMM block to contribute the A-SMGCS display.

Figure 3-18 illustrates the embedded program flowchart for AMM display block.

There are two subunits for different alerting severities, as a compliance with the principles descripted in Chapter 3.3.6.2. The computation for alert initialization is not simply comparing the preset safe space with the updated distance between two targets, but conducting detection parameters which change their values when proximities happening; and the logic defining the alert order is also taken into account in the program.

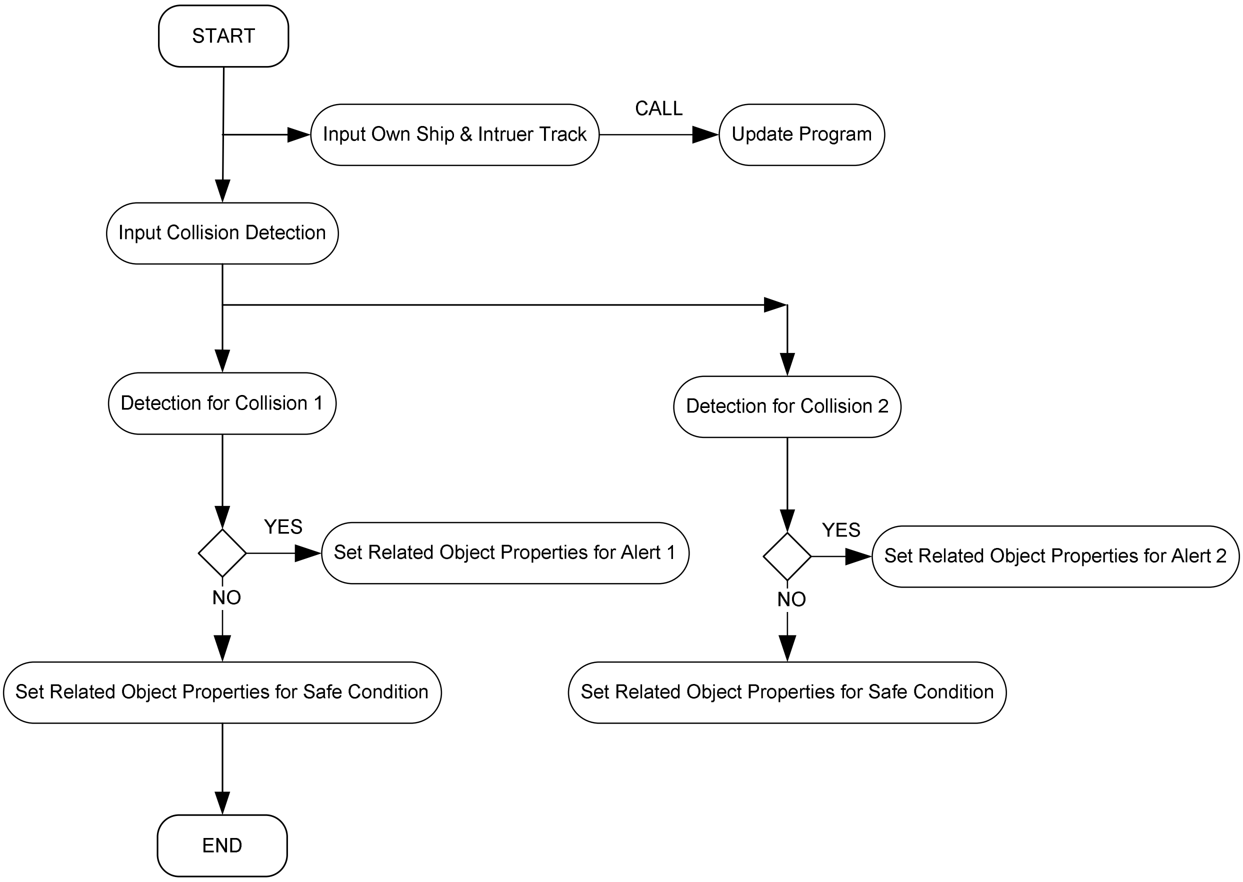


Figure 3-18 Embedded program flowchart for AMM display block

3.3.8 Clearance Assigning Interface

3.3.8.1 Configuration

The Clearance Assigning Interface is desinged in the simulation to support the route planning. The inputs entered into the GUI window initial the switch function in target track database, and the according routing will be presented on the AMM. The implementation could be seen in Figure 3-4.

The practical ATC interface has been defined by designing a GUI. The GUI here is developed as a path plan setting window. Double clicking the GUI model, there are two list boxes provided to the user, with the name of ownship Setting and the Other Target (as an intruder in operation) respectively; for every box there are two pull-down menus supplying selection of taxiways and the corresponding hold points on each of them. As shown in Figure 3-19.

This GUI layout is for the target track setup in simulation. To implement a GUI practically for the ATC application, more design for GUI in the future work must be conducted to show the airport map with legends for each pathway and stops.

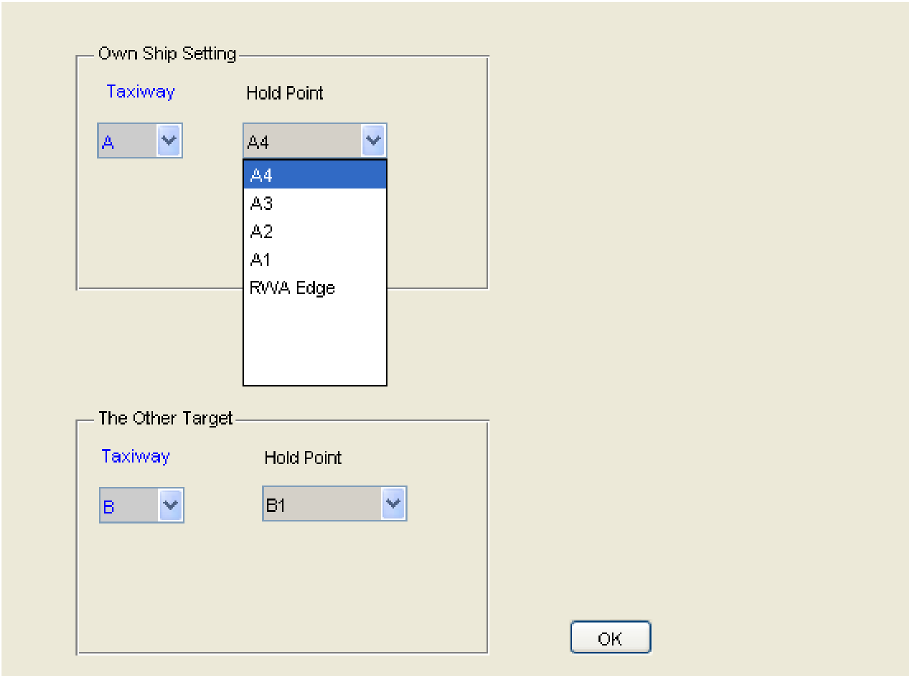


Figure 3-19 GUI for clearance

3.3.8.2 Operation Instructions

The clearance data is in the pull-down menus. Single click the list box and highlight the desirable parameters, then click to select this setting. First select the taxiway; once selected the other list box containing the hold points will e updated and only include the possible hold points on that taxiway. Repeat for the target settings. After finishing the assignments, click the OK button on the downright corner to save the parameters.

The operational instructions for clearance assigning are presented in Appendix D.

When the clearance assigning operation has finished, clicking the OK button will save the operation results and close the GUI window.

4 Simulation Results

As a basic compliance with the A-SMGCS system performance requirements form ICAO manual [2], and an implementation for the simulation algorithm in Chapter 3, the simulation results are presented as videos, covering contents as:

- An AMM with Cranfield airport layout;
- Two targets, one as ownship and the other as intruder, moving on the main surface paths;
- Incursion alerts on two severity levels;
- Runway occupation indication;
- Pause for movement when high-severity alert or runway occupation indication comes out.

As pointed out in Chapter 3.3.4, the vehicle size and initial speed are constant and that no attempt has been made to model realistic acceleration and braking.

4.1 Simulation Cases

4.1.1 Taxiway Movements

The following cases describe the following A-SMGCS applications related to taxiway movements:

4.1.1.1 Case 1

Without collision: the ownship pilots are allowed the view of normal traffic on surface taxiways, including the ownship positions, other target positions and the corresponding ID; the specific simulation conditions are listed in Table 4-1.

Table 4-1 Taxiway movement case 1

<table>
<tr><th>Target</th><th>From</th><th>To</th><th>Holding Point</th><th>Collision Condition</th><th>Alert</th></tr>
<tr><td>Ownship</td><td>Apron 4</td><td>RWA Edge</td><td>RWA Edge</td><td rowspan="2">No proximity</td><td rowspan="2">No alert</td></tr>
<tr><td>Iintruder</td><td>Runway</td><td>Apron1</td><td>B1</td></tr>
</table>

4.1.1.2 Case 2

With collision: the ownship pilots are provided with alerts generated with three phases which respectively are:

- The ownship crews that the intruder has passed the hold point behind it and there is only one hold point for the ownship to stop, Category B alert is triggered (Chapter 3.3.6.2);
- The distance between the ownship and intruder is less than St (Equation 2-1), Category A alert is triggered (Chapter 3.3.6.2) to indicate the ownship to brake as soon as possible;
- The ownship movement pauses as an response to the Category A alert.

The specific simulation conditions are listed in Table 4-2.

Table 4-2 Taxiway movement case 2

<table>
<tr><th>Target</th><th>From</th><th>To</th><th>Holding Point</th><th>Collision Condition</th><th>Alert</th></tr>
<tr><td>Ownship</td><td>Apron 4</td><td>RWA Edge</td><td>RWA Edge</td><td rowspan="2">Proximity</td><td rowspan="2">Alerts</td></tr>
<tr><td>Intruder</td><td>Runway</td><td>Apron1</td><td>Apron1</td></tr>
</table>

4.1.2 Runway Occupation

The following cases describe the following A-SMGCS applications related to runway movements:

When there is other target on runway area, the ownship pilots are offered the view of runway occupation warning; based on this warning the pilots are allowed the option of stopping the aircraft at runway Hold Short Lights untill the runway is cleared, instead of waiting on the taxiway holding bar; this operation is more time-saving , subsequently capable of reducing airport delays.

The specific simulation conditions are listed in Table 4-3.

Table 4-3 Runway movement case 1

Target	From	To	Holding Point	Collision Condition	Alert
Ownship	Taxiway A	Runway End	Runway Hold Short Lights	No collision	Runway Occupation Warning
Intruder	Taxiway C	Taxiway E	Taxiway E		

4.2 Simulation Scenarios

4.2.1 Taxiway Movements

4.2.1.1 Case 1

The sectional drawing of the simulation video are listed as following, to present the minor phases of the implementation results.

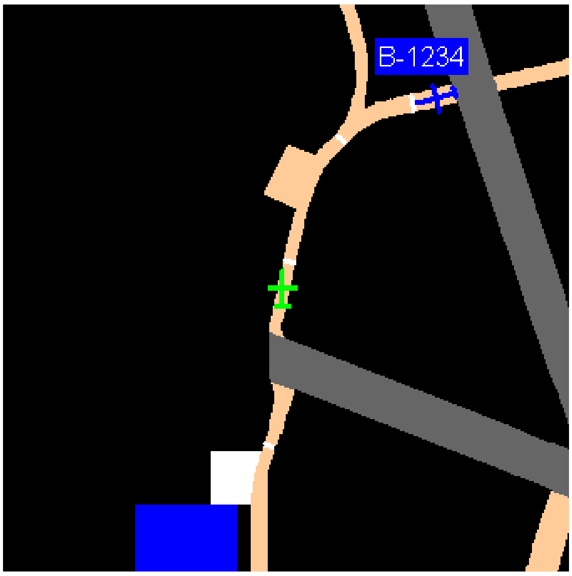


Figure 4-1 Taxiway movement without collision

4.2.1.2 Case 2

The sectional drawing of the simulation video are listed as following, to present the minor phases of the implementation results.

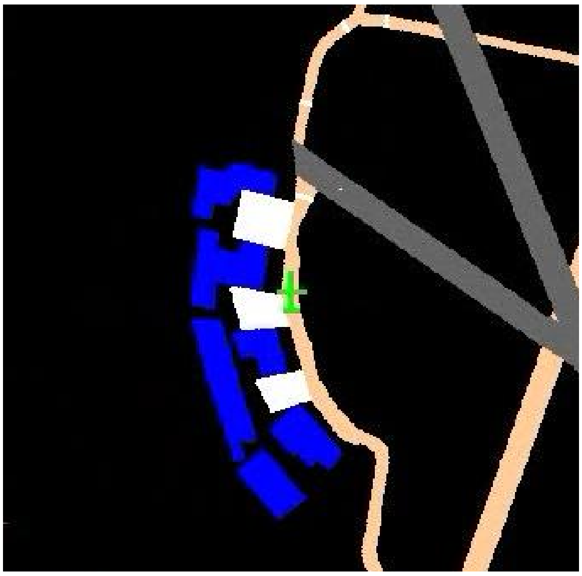


Figure 4-2 Ownship moves on taxiway A

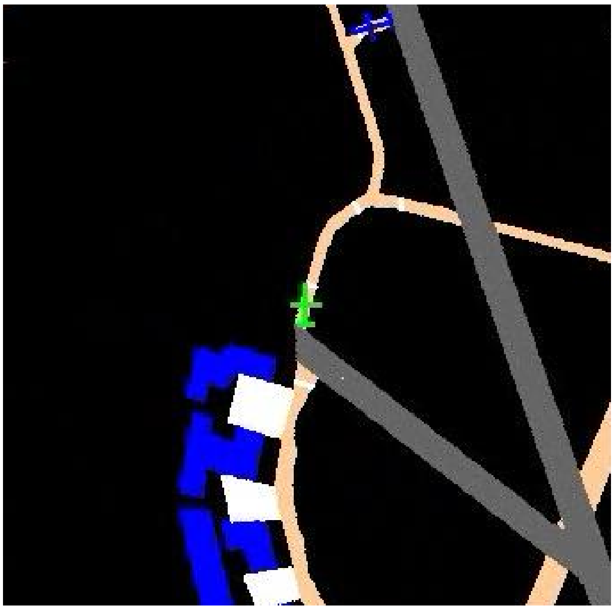


Figure 4-3 Intruder moves on taxiway B, with hold point B1, A2, A3 between the ownship and intrder

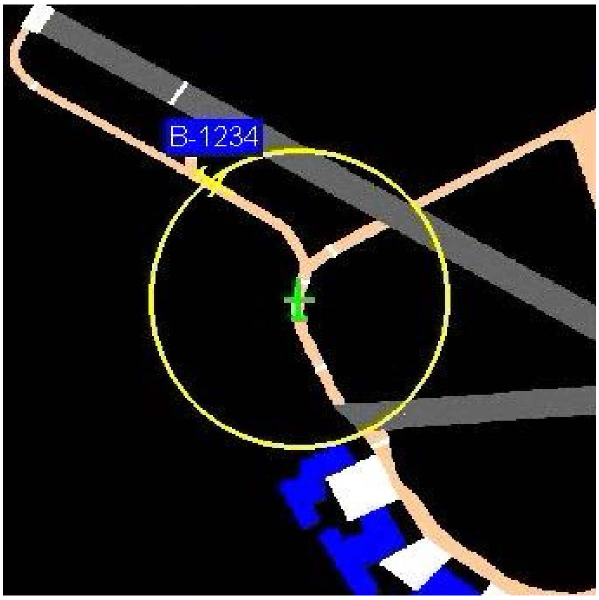


Figure 4-4 Intruder has passed the hold point behind it and there is only one hold point for the ownship to stop

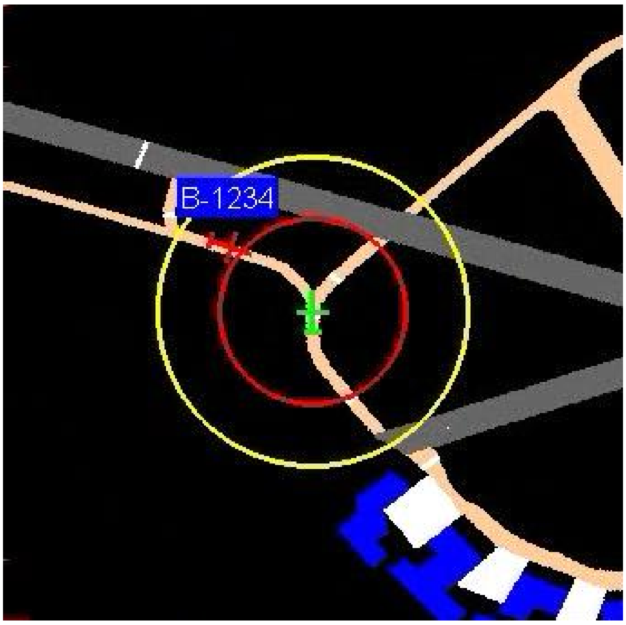


Figure 4-5 The distance between the ownship and intruder is less than St (Equation 2-1)

4.2.2 Runway Occupation

The sectional drawing of the simulation video are listed as following, to present the minor phases of the implementation results.

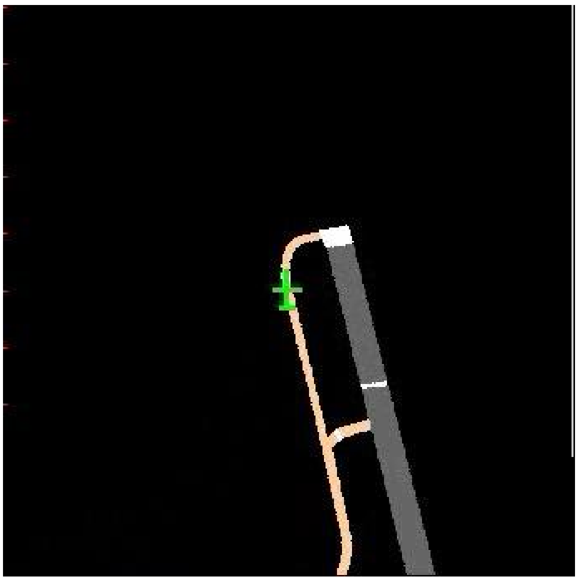


Figure 4-6 Ownship moves on Taxiway A and towards the Runway

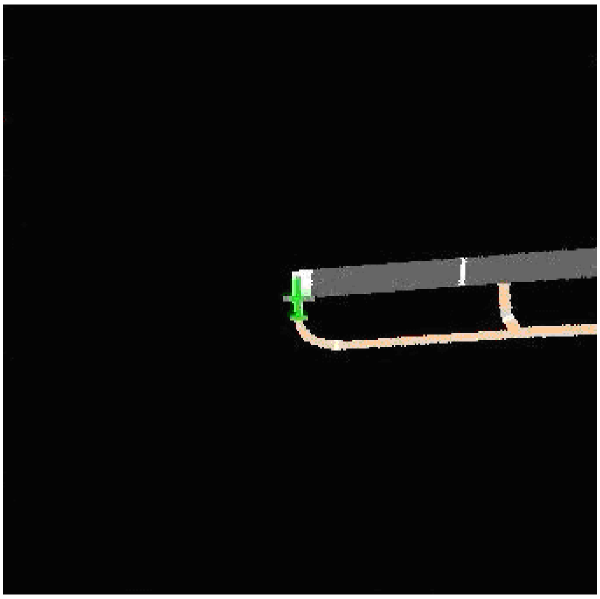


Figure 4-7 Ownship on Runway Edge

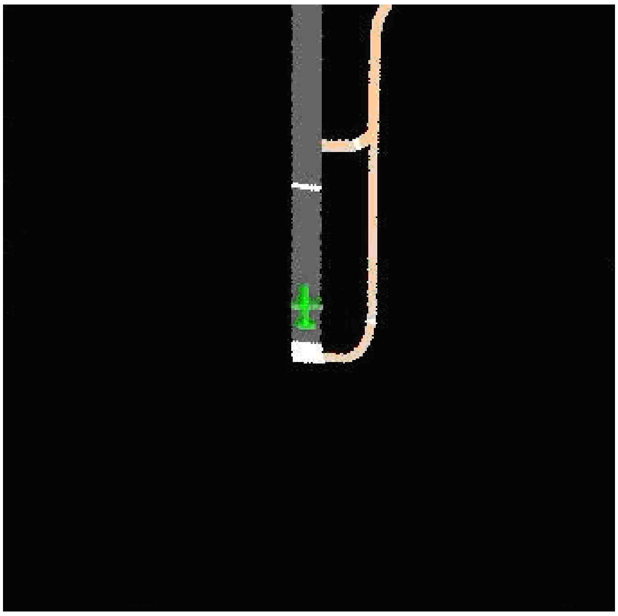


Figure 4-8 Ownship moves on runway before Runway Hold Short Lights

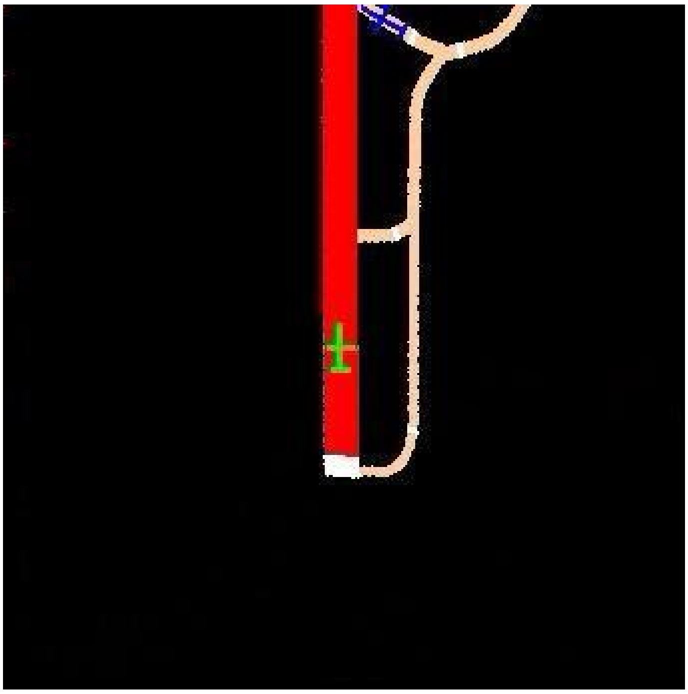


Figure 4-9 Intruder moves close to runway; Ownship stops beforeRunway Hold Short Lights

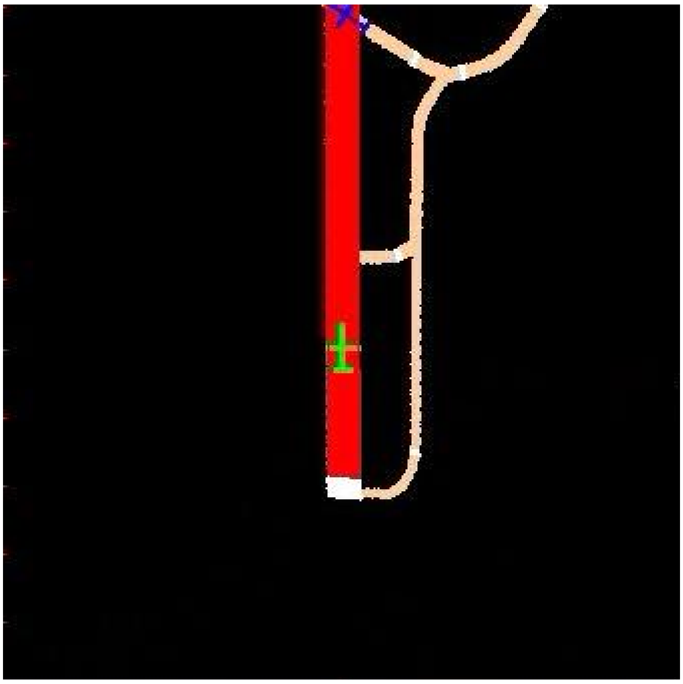


Figure 4-10 Intruder moves on runway; Ownship stops before Runway Hold Short Lights

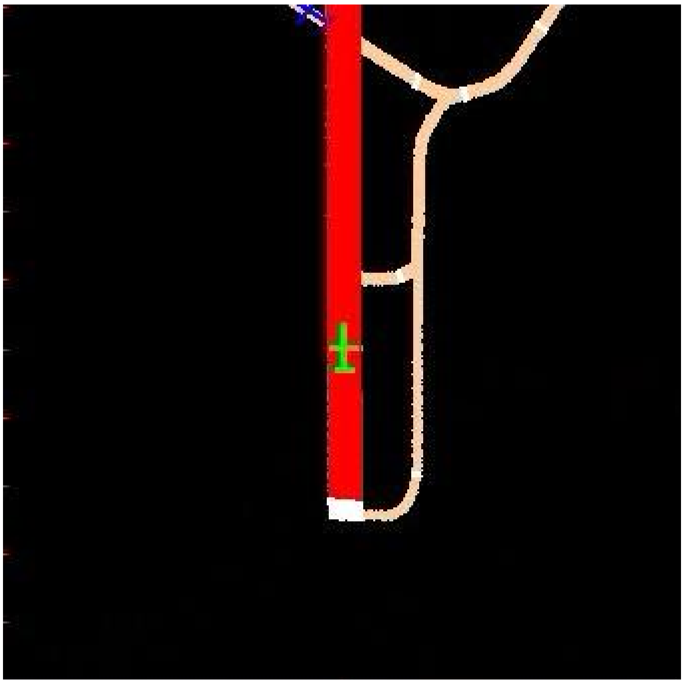


Figure 4-11 Intruder moves on runway; Ownship stops before Runway Hold Short Lights

Figure 4-12 Intruder leaves runway; Occupation warning disappears

5 Discussion and Conclusion

5.1 Completed Tasks and Current Limitations

The work developed and finished in this project produced the following results:

- An investigation on the A-SMGCS and its incidental technologies, covering the system concept, history, developing backgrounds, industry standards, and applications combined with the subsystem operations.

- An analysis of the statistical documentary on airport collisions and delays, from which the surface incursion definition, classifications, and severities were presented.

- A definition to the system, including the A-SMGCS philosophy and benefits, illustration of the system function and configuration, system architecture demonstration, and an explanation of the operation of the integrated subsystem.

- An implementation for the main A-SMGCS function requirements, separated as target track database design, GUI design, and AMM block design. The AMM integrated image processing programming, alert generating blocks, and AMM map display program. The users are provided with the GUI and AMM display.

This project provides a survey for the A-SMGCS system, giving an introduction of its technology background and industry environment. The survey also leads to an evaluation of the system advantages, relating to current airport operation. This part establishes a basic foundation for the implementation and development for an A-SMGCS.

The demonstrations of the A-SMGCS functions and architecture offer a detailed description of the implementation aims. By achieving the existing performance standards, the tasks for simulation, both conducted in this projects and in possible future work, could be identified specifically.

Implementation for A-SMGCS functions is produced in this project as the core work. The simulation works basically consist of three main units: GUI, target track database, and AMM block.

The GUI is developed with a window allowing users to plan a routing plan for the ownship and intruder movements. This interface could be either programmed to work with the current target track database, or simply modified to be applied to expanded operations, such as there are more than one moving targets, or other traffic in a flight environments.

The track database is according to the GUI design, with interface to GUI commands and AMM blocks. The target movement positions and corresponding time are allocated in this database for AMM and GUI invoking.

The AMM block takes the target track database as surveillance signal input, and generates AMM display as output. Integrated within this block, there are sub units for function implementations as:

- Digital map generating;
- Alert generating;
- AMM display generating.

The AMM display provides the users with an A-SMGCS HMI display, including information of the ownship and intruder movement, ID indication, and collision alerts.

To adjust the AMM collision alerting radius you could change the safe spacing alerting circle radius, correspondingly the separation indication and alert rule changes.

The AMM design is expandable for display diversification; it is also adjustable for the GUI and target track database input developments.

As a summary, in this project the following work was completed for the A-SMGCS:

- Airport traffic collision analysis and definition;
- System principle and function requirements;
- System Layout and architectures;
- System function implementations.

Due to the study time which is not sufficient for a fully simulation to A-SMGCS functions, there are following limitations in the implementation of this project:

- The AMM zoom level is not adjustable, but considered as automatically modified to a proper level for the user;
- The targets moving on AMM are designed with constant speed and size, and no attempts have been made to model realistic acceleration or breaking;
- The GUI layout is not capable to reflect all the useful airport surface information for a completed ATC planning.

5.2 Future Work

The following items could be conducted for A-SMGCS implementations and integrations in future work:

- To introduce more than one intruder;
- To simulate more collision geometries;
- To cover navigation functions;
- To design the surveillance and data link communication unit;
- To design automatic emergent routing alternation and related airport surface collision avoidance function;

- To enable AMM with zoom in/out capability;
- To initial AMM targets with realistic speed and size;
- To define the accurate value of proximity distance for incursion alerts value;
- To develop GUI windows to a more complete and practical level.

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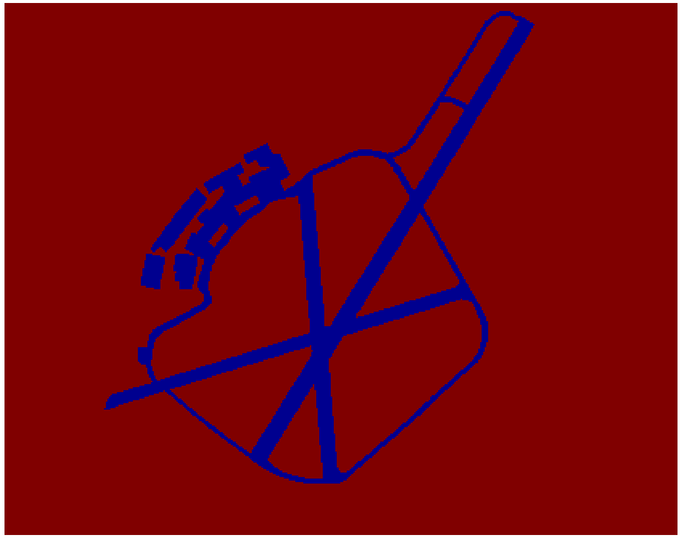
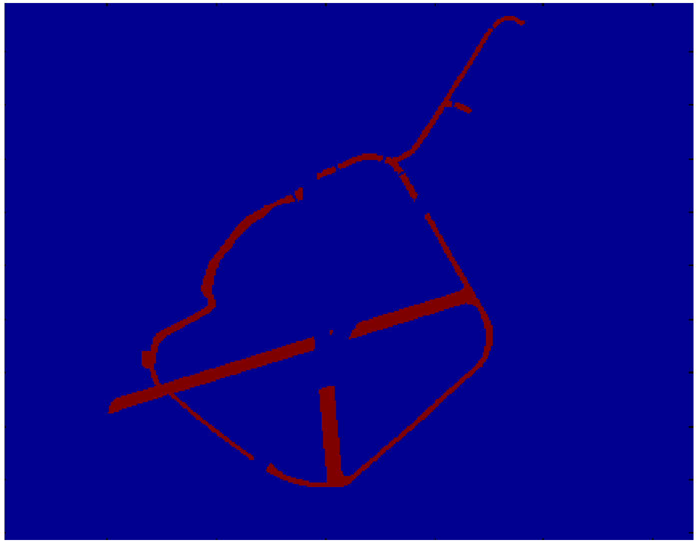
APPENDIX A Airport Movement Operation Approach Comparison

Operator	Airport traffic surveillance	Movement routing	Information delivery	Collision awareness /alerting/routing switching
Traditional ground controller	SMR; Audio reports from onboard personnel.	Memorize the routing navigation; Send the routing plan to onboard personnel by audio communication.	Audio communication.	SMR.
A-SMGCS supports for ground controller	SMR; SSR; ADS-B; Digital and audio reports from onboard personnel.	AMM; Routing selection form Digital and audio information delivery.	Audio communication; Different data link technologies, including Mode-S Extended Universal Access Transceiver and VHF Data Link (VDL Mode 4).	SMR; ADS-B; Automatic alerting.
Traditional pilots/vehicle drivers	Visual observation; Audio indications from ground.	Depend on airport routing pointing paper chart; Follow the audio routing indications from ground.	Audio communication.	Visual observation; Ground audio collision alerting.

Operator	Airport traffic surveillance	Movement routing	Information delivery	Collision awareness /alerting/routing switching
A-SMGCS supports for pilots/vehicle drivers	Visual observation; AMM; Digital and audio indications from ground.	Routing display on AMM; Follow the digital and audio routing indications from ground.	Audio communication; Different data link technologies, including Mode-S Extended Universal Access Transceiver and VHF Data Link (VDL Mode 4).	Visual observation; AMM collision prediction display; Ground digital and audio collision alerting.

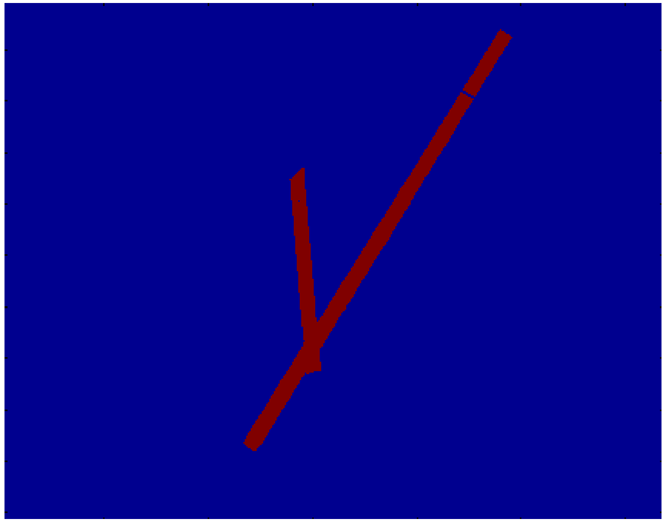
APPENDIX B Image Filtered Layers



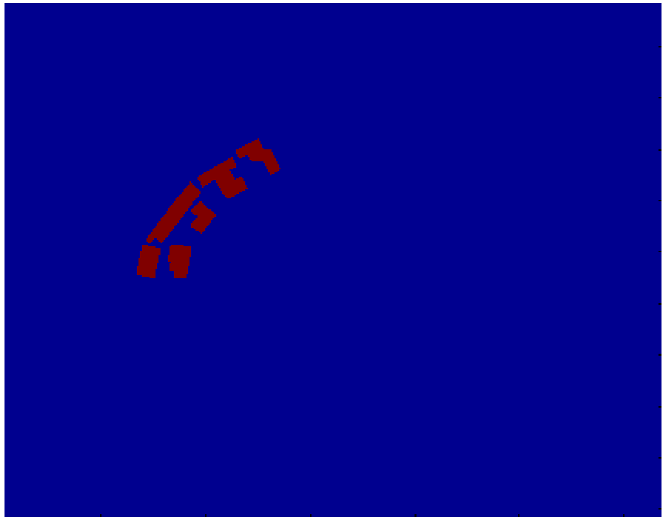


Background layer

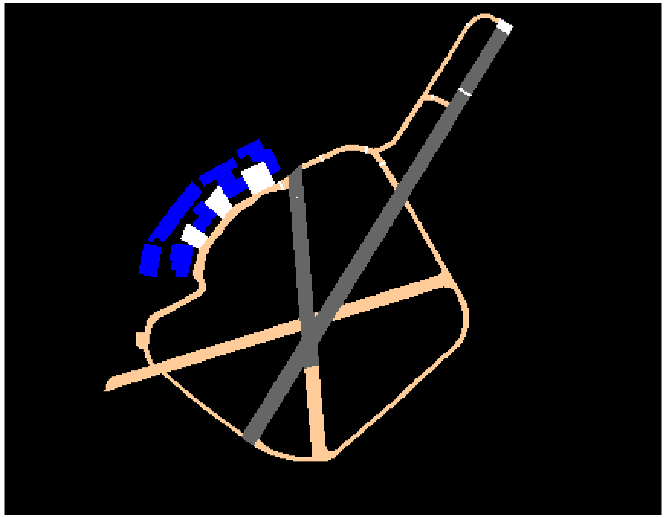
Taxiway layer



Runway layer



Building layer



Composed map

APPENDIX C Codes for Image Filtering

```
%Filtering of Background

ReferenceBackground=AirportMap(200,120,:)

ColourSpreadBackground=7;

Background=AirportMap(:,:,1)<ReferenceBackground(1)+ColourSpreadBackground&AirportMap(:,:,1)>
ReferenceBackground(1)-ColourSpreadBackground&...


AirportMap(:,:,2)<ReferenceBackground(2)+ColourSpreadBackground&AirportMap(:,:,2)>ReferenceBa
ckground(2)-ColourSpreadBackground&...


AirportMap(:,:,3)<ReferenceBackground(3)+ColourSpreadBackground&AirportMap(:,:,3)>ReferenceBa
ckground(3)-ColourSpreadBackground

figure(2)

image(Background*255)

%Filtering of TaxiWays
```

```
ReferenceTWA=AirportMap(390,500,:)

ColourSpreadTWA=17;

TWA=AirportMap(:,:,1)<ReferenceTWA(1)+ColourSpreadTWA&AirportMap(:,:,1)>ReferenceTWA(1)-
ColourSpreadTWA&...

    AirportMap(:,:,2)<ReferenceTWA(2)+ColourSpreadTWA&AirportMap(:,:,2)>ReferenceTWA(2)-
ColourSpreadTWA&...

    AirportMap(:,:,3)<ReferenceTWA(3)+ColourSpreadTWA&AirportMap(:,:,3)>ReferenceTWA(3)-
ColourSpreadTWA;

figure(3)

image(TWA*255)

%Filtering of RunWays

ReferenceRWA=AirportMap(608,652,:)

ColourSpreadRWA=6;

RWA=AirportMap(:,:,1)<ReferenceRWA(1)+ColourSpreadRWA&AirportMap(:,:,1)>ReferenceRWA(1)-
ColourSpreadRWA&...
```

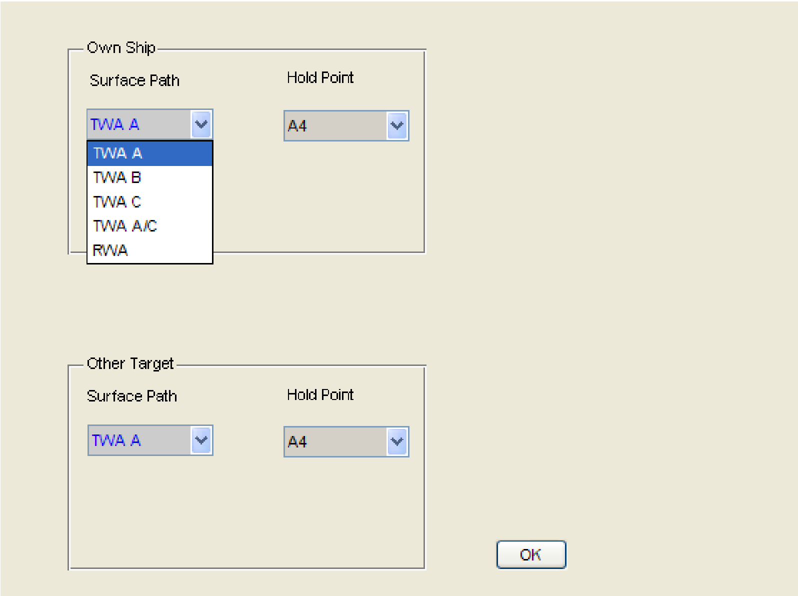
```
    AirportMap(:,:,2)<ReferenceRWA(2)+ColourSpreadRWA&AirportMap(:,:,2)>ReferenceRWA(2)-
ColourSpreadRWA&...

    AirportMap(:,:,3)<ReferenceRWA(3)+ColourSpreadRWA&AirportMap(:,:,3)>ReferenceRWA(3)-
ColourSpreadRWA;

figure(4)

image(RWA*255)

%Filtering of Buildings

ReferenceBuilding=AirportMap(390,440,:)

ColourSpreadBuilding=50;

Building=AirportMap(:,:,1)<ReferenceBuilding(1)+ColourSpreadBuilding&AirportMap(:,:,1)>Refere
nceBuilding(1)-ColourSpreadBuilding&...


AirportMap(:,:,2)<ReferenceBuilding(2)+ColourSpreadBuilding&AirportMap(:,:,2)>ReferenceBuildi
ng(2)-ColourSpreadBuilding&...
```

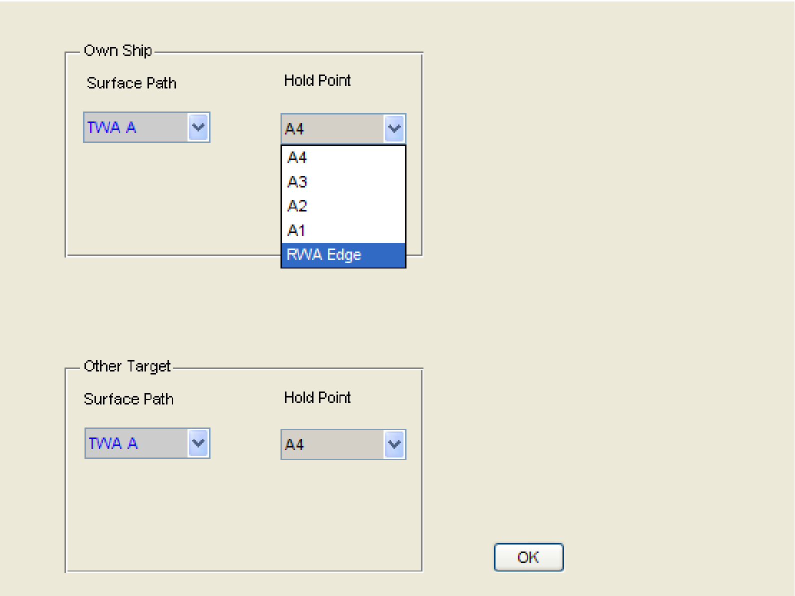
```
AirportMap(:,:,3)<ReferenceBuilding(3)+ColourSpreadBuilding&AirportMap(:,:,3)>ReferenceBuildi
ng(3)-ColourSpreadBuilding;

figure(6)

image(Building*255)

%Filtering of Apron

ReferenceApron1=AirportMap(255,750,:)

ColourSpreadApron1=[33 3 46];

Apron1=AirportMap(:,:,1)<ReferenceApron1(1)+ColourSpreadApron1(1)&AirportMap(:,:,1)>Reference
Apron1(1)-ColourSpreadApron1(1)&...


AirportMap(:,:,2)<ReferenceApron1(2)+ColourSpreadApron1(2)&AirportMap(:,:,2)>ReferenceApron1(
2)-ColourSpreadApron1(2)&...


AirportMap(:,:,3)<ReferenceApron1(3)+ColourSpreadApron1(3)&AirportMap(:,:,3)>ReferenceApron1(
3)-ColourSpreadApron1(3);
```

```
figure(7)

image(Apron1*255)

%Composing

FullDisplay=Background*1+TWA*2+RWA*3+HoldingBar*0+Building*5+Apron1*6+Apron2*7+Apron3*8+Apron
4*9;

figure(11);

FullDisplay_8bit=uint8(FullDisplay);

image(FullDisplay_8bit);%not multiply 255 to avoid the value overflow 255 (lead to non
display of that part)

%Colour Assignment

ColorAssign=[255,255,255;

             255,204,153;

             102,102,102;

               0 , 0,  0;
```

```
                0,   0,   0]/255;

image(FullDisplay);

colormap(ColorAssign);
```

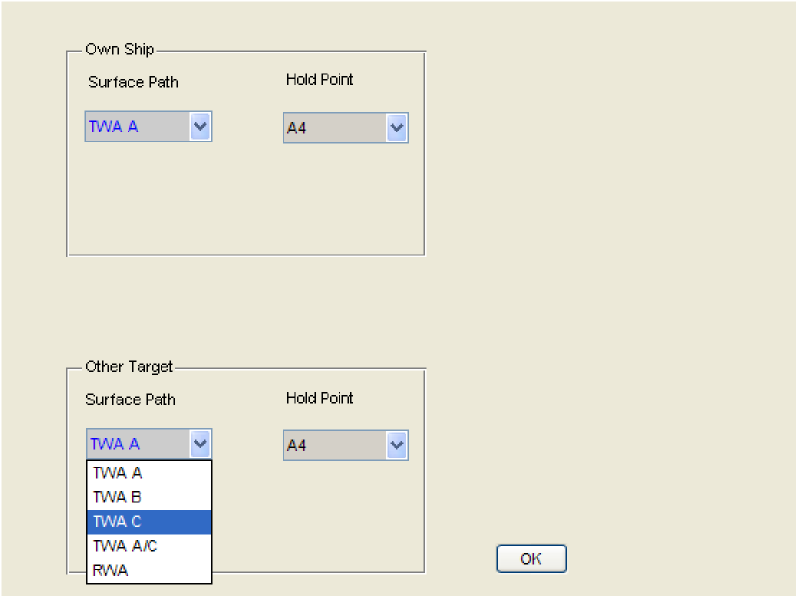
APPENDIX D Instruction for Clearance Assigning



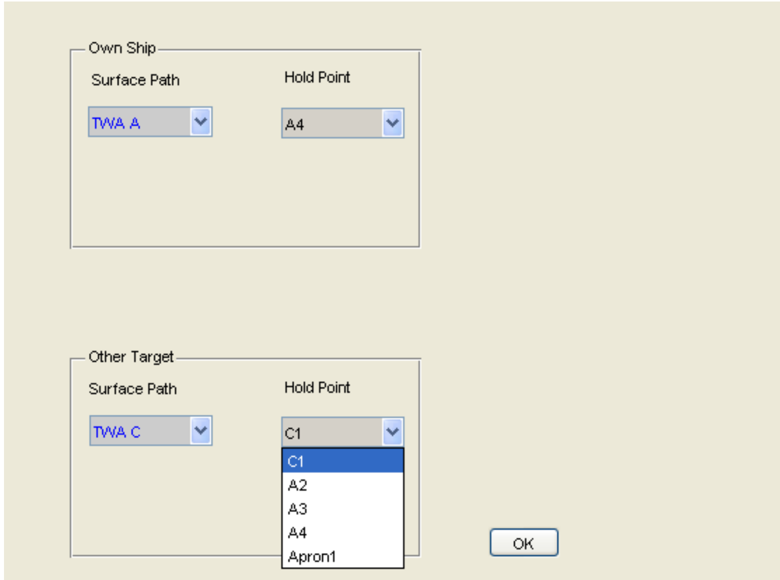


Step 1: Chose a taxiway A for the ownship track;

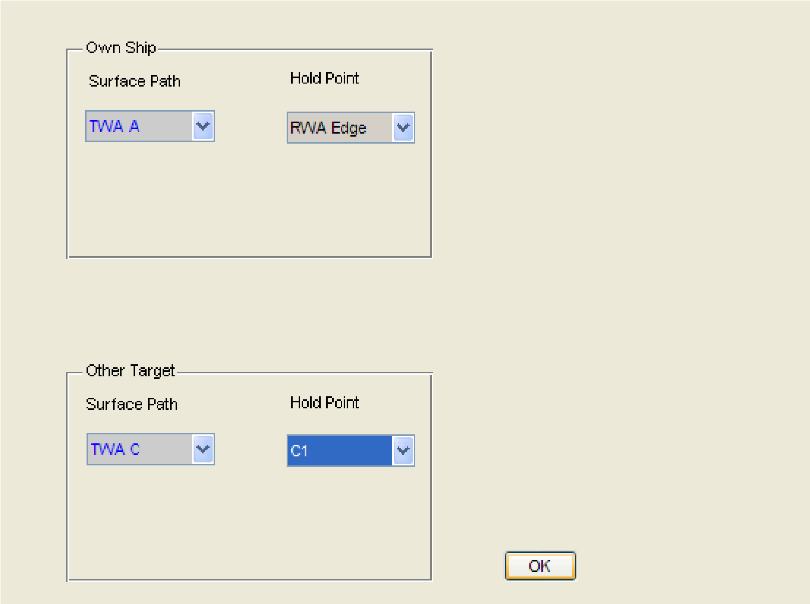
Step 2: Chose a hold point of the runway edge on taxiway A for the ownship;



Step 3: Chose a taxiway C for the intruder track



Step 4: Chose a hold point of C1 on taxiway C for the the intruder



Step 5: Finish assigning

APPENDIX E Group Design Report

COCKPIT DISPLAY LAYOUT AND ADVANCED AVIONICS

TECHNOLOGIES OF PHOENIX AIRCRAFT

ABSTRACT

The overall content of this article as part of the COMAC GDP report is divided into three main areas. Firstly, the display layout in cockpit based on human factor consideration is illustrated, including the locations of the displays and the initial arrangement of split screen space for significant information shown to the crews. Secondly, advanced avionics technologies are demonstrated here, which is relative to the human interface machines set in the cockpit as the terminal components of the whole system.

CHAPTER 1: INTRODUCTION

1.1 Background

The recent development of avionics technology brings increasingly complex information and control systems into practical areas so that people need to learn to interpret more completed machines. To this problem one of the approaches has been to develop graphical interfaces with symbols integrated on a higher level. The recent research aiming to improving the human-machine interface is mainly motivated by giving attention to time-consumption, flight safety, operator overload, and training cost.

1.2 Advanced Avionics Technologies

The concept of integrated vehicle health management (IVHM) is an evolution of onboard systems with diagnostic and prognostic function by offering cautious information and disposing suggestions displayed to the pilots. The expectation of the technology is to achieve an implement of advanced prognostics and health management (PHM) strategy that enables the following services:

- Continuous monitoring and real-time assessment of vehicle functional health;
- Predicting near failure components and remaining useful life of fault;
- Improving operational decisions by using this information.

The Advanced Surface Movement Guidance and Control Systems (A-SMGCS) concept implements airport surface movement management function by requiring the surveillance of all aircraft and vehicles in the airport movement area, providing controllers and pilots the movement maps on a display in the ground stations and aircraft cockpits with the locations of all surface traffic , periodically updating synthetic image reflecting the current traffic state on the airport surface, transmitting airport traffic control data including rutting planning and proximity alerting, enabling vehicle separation and guidance even in low-visible weather conditions without effecting the efficiency of operation or the level of safety.

CHAPTER 2: COCKPIT DISPLAY LAYOUT

2.1 Background

The early instruments were sometimes just pieces of string to indicate sideslip, and owe to the development of mechanical technology, at least one company combined all the flight instruments into a single instrument panel appearing as a concept to reappear later in the context of the "glass cockpit", which can be said to be the first example of an integrated PFD (primary function display). (Smith Aerospace)

The integrated panel comprised:

- Airspeed ;
- Altimeter;
- Vertical speed;
- Engine tachometer;
- Stopwatch;
- Slip indicator.
- The cockpit could also include:
- Attitude;
- Compass indicator;
- Clock.

The evolution of the electromechanical technology provided the feasibility to the implement of integrated electromechanical instruments in the cockpit.

Nowadays the display systems and information formats have to be improved to a more integrated and graphical philosophy to meet the human operational challenges relative to the advanced avionics technologies.

2.2 Design philosophy and benefits

The pilot is supposed to be the final authority for the operation of the airplane, and the following features of displays layout are mainly based on the following considerations:

Both crew members should be ultimately responsible for the flight operation safety;

In the order of priority the flight crew tasks are: safety, passenger comfort, and efficiency;

Design for crew operations should be based on the past training and operational experience of the pilots;

Systems should be designed to be error-tolerant;

The whole philosophy of the design alternatives hierarchy is: simplicity, redundancy, and automation;

Automation is supposed to be applied as a tool to support, not replace, the pilot;

Fundamental individual differences including human strengths and limitations should be addressed–for both normal and non-normal operations;

New technologies and functional capabilities could only be utilized when:

They result in clear and distinct operational or efficiency advantages, and

There are no negative impacts to the human-machine interface.

Based on the design philosophy above it is not difficult to demonstrate the advantages from the display layout including:

Simplicity that contributes to low-cost of manufacture and maintenance process;

Operational commonality resulting in reduced training cost;

Being integrated on a high level for a bigger amount of information and open to more optional functions, this illustrates optimum features capable for growth and advanced technology.

2.3 Layout configuration

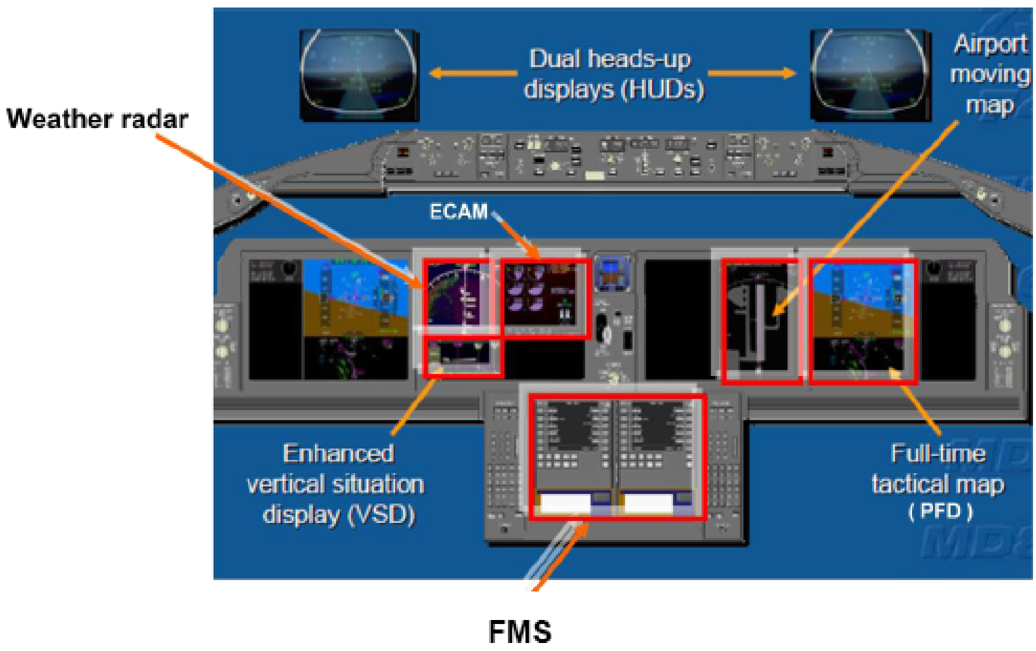


Fig.1. Displays on the top panel and central deck

Fig.2. UHD for pilot

Fig.3. Side displays

2.4 Brief function description

PFD (Primary Function Display): Full-time tactical map with integrated navigation and navigation performance scales (PFD & ND information);

Airport moving map: the terminal components of the A-SMGCS;

FMS: the flight plan is uploaded into the FMS (Flight Management System) computer and displayed to the crews on the FMS CDU (Control and Display Unit) ;

ECAM (Electronic Centralized Aircraft Monitor): the ECAM is supposed to be relative to IVHM (Integrated Vehicle Health Management system) and provide continuously monitoring for onboard systems performance and reports back to the central processer. The information provided includes total fuel state, outside air temperature, and “MEMO” items which remind the crew whether the systems and functions are in operation, that are only used temporarily and could be forgotten. It could also be displayed to the pilot that the malfunctions in plain language/checklist form and the necessary corrective action.

Enhanced VSD (Vertical Situation Display): the VSD offers an intuitive view of the vertical situation to the crews just as the current map display provides an intuitive depiction of the lateral situation, the sources of which include barometric and radio altitude readouts, the vertical speed indicator, ground proximity warning systems, terrain depiction systems, navigation information from the FMS, and navigation charts.

Weather radar: to detect the intensity and three-dimensional structure of the precipitation beneath the large cloud shields.

HUD (Head-up Display): located at the head-up position of the pilot with flight- or mission-critical information by the application of HUD in a form that is conformal, that is, in “contact analogue” with his real-world view. The information in this display could include:

Situational awareness and thus safety to the landing approach in the following areas: conformal symbols such as deviations relative to the aircraft’s ideal runway approach path, runway central line, glide-slope reference line, path vectors, acceleration/deceleration cues, optimum guidance;

Heading;

Flight path vector/marker (velocity vector);

Attitude (pitch and roll);

- Longitudinal acceleration;
- Horizontal line;
- Airspeed;
- Groundspeed;
- Terminal information symbols from A-SMGCS (Advanced-Surface Movement Guidance and Control system);
- Vertical speed (rate of climb-dive);
- Angle of attack.

Side displays: the two side displays are located on both sides including the functions optional for airline or third party software applications platform, such as the following items:

- Computation of performance data;
- Video surveillance;
- Navigation charts;
- Electronic documents;
- Electronic logbook;
- Electronic checklist;
- Electronic flight bag;

CHAPTER 3: IVHM

3.1 Definitions and benefits

Currently there is still no unanimously or even generally accepted definition of IVHM (Integrated Vehicle Health Management system), consequently by comparing the various existing interpretations the concept of IVHM can be regarded as ‘the capture of vehicle condition, both current and predicted, and the use of this information to enhance operational decisions, support actions, and subsequent business performance’.

From varies sensors and data processing units, health data are collected from the whole vehicle, including components, structures, and elements , which are used to make diagnoses and prognoses of the present and future health of the vehicle. In addition, this information is further processed to formulate appropriate operation and actions supporting suggestion presented to the crews to decide and execute the actions.

Here, the first critical issue is that besides only processing health data and presenting them for later operation and use the information evaluating vehicle condition must be applied upon to generate reactive plans. This is the key difference of the philosophy of health management from health monitoring, according which there is no requirement to specify the subsequent action about the data collected.

The second critical issue owes to the concept of integration. The health management system will consider the vehicle as a whole; it will merge all vehicle functions rather than be implemented separately on individual subsystems, components, and elements. In comparison to the classical philosophy of regarding the processing object as a federated system consisting of loosely components, the single IVHM system will help streamline isolation of failures as well as improving decision-making in fault conditions by considering the overall aircraft behaviour.

On these bases, an IVHM system can be considered as an advanced vehicle instrumentation system with the following points highlighted:

- Enabling cost-effective ultra-high system availability;
- Ensuring operation safety;
- Enabling the proposition of seeing the IVHM as a quality management tool in a wider sense.

3.2 System architecture

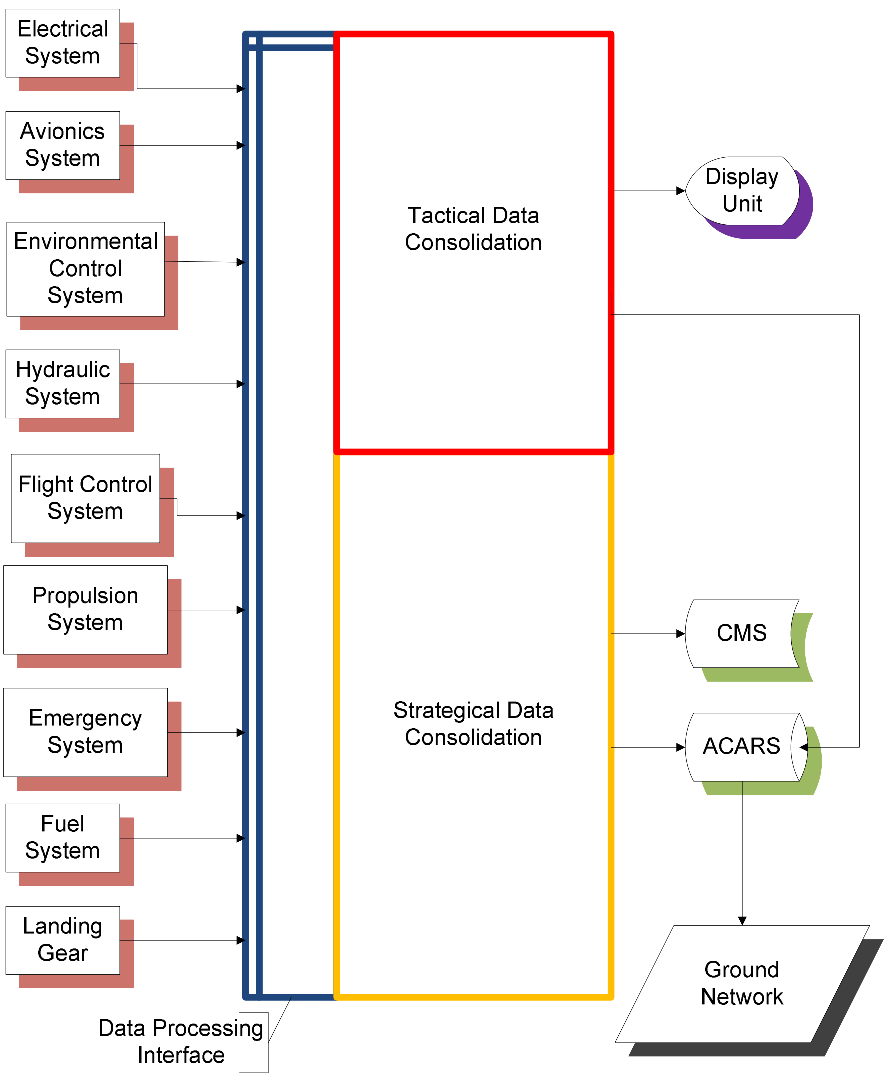


Fig.4. IVHM block diagram

3.3 Implementation

The IVHM could be regarded as one kind of on board maintenance system with a firewall linked to the air-to-ground ACARS and the cockpit display interfaces as terminal user units.

As illustrated in Fig.4, to support the whole function of diagnoses and prognoses, the controller has some logic to perform basic determination of the potential dangerous degree category and limit or rate of checks on components and their sensors in subsystems. In some cases when redundant sensors disagree, on-board component models are used in conjunction with the controller's own sensor voting scheme to help judge which sensor is correct.

To meet the requirements of affectivity and efficiency in information management, the monitoring data processing unit is designed to separate into two main parts based on different philosophies:

The tactical data consolidation mode is responsible for the data needed to be processed in short-team and then be acknowledged real-timely by the onboard crews and ground;

The strategically data consolidation mode is doing long-term process of the data for the maintenance work after landing, and that information could both be stored onboard or transmitted to the ground though air-ground data link.

The process of confusion and the classification to the health information data collected from subsystems are conducted in the data processing interface integrated in the control computer onboard.

CHAPTER 4: A-SMGCS

4.1 Definitions and benefits

The concept of A-SMGCS includes a comprehensive surveillance element capable of the location and classification of all aircraft and vehicles within the area of interest and the identification of cooperative aircraft and vehicles, and it is also including the capabilities of utilizing the comprehensive surveillance data to work with a set of rules which will enable the system to alert the user to potential dangerous situations.

By using the technologies shown in Table.1, the pilots' operations in the airport area can be improved by their capability of realizing: (1) their position relative to runway/taxiway edges, (2) which runway or taxiway they are currently on and planning to have route to, (3) the potential intersection from the taxiways to the occupied runway, and the names and locations of them, (4) the modification of the route planning.

Generally speaking, the information provided by the A-SMGCS is displayed to the crews in the cockpit in includes:

- The moving map -- track-up airport surface display with ownship situation, relative traffic and graphical route guidance; on the top panel as shown in Fig.5, Fig.6 and Fig.7.
- Scene-linked symbologies -- route/taxi information virtually projected onto the forward scene; via a Head-up Display (HUD) for the pilot.

Acknowledgement about the benefits that can be expected from A-SMGCS plays a key role in motivation on A-SMGCS development. Only if the benefits are identified and quantified, and if the technological and operational feasibility is sufficiently demonstrated, the relevant decision makers will include ASMGCS in their investment plans.

CHAPTER 5: CONCLUSION AND FUTURE WORK

In this part of COMAC GDP, the article demonstrates the initial cockpit layout philosophy and the advanced avionics system brief architectures relative to the display configuration, which consist of several new avionics technologies.

The future work could be conducted in the following areas:

To complete the system architectures in this article by implementing them in a more detailed way;

To establish a whole avionics system configuration with the subsystems united together practically.

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