The Drift of the Xsens Moven Motion Capturing Suit during Common Movements in a Working Environment

R.G.J. Damgrave, D. Lutters
Laboratory of Design, Production and Management, Faculty of Engineering Technology
University of Twente, Enschede, The Netherlands
r.g.j.damgrave@utwente.nl; e.lutters@utwente.nl

Abstract
When using inertial motion capturing technology, the accuracy of the results is strongly influenced by the so-called drift. This paper describes the drift of an Xsens Moven motion capturing suit during common movements, measured in a standard working environment. The test is performed in a room not shielded from magnetic disturbances, to acquire insight on how accurate the absolute position determination of the motion capturing system is during use in a standard environment. The test is performed by walking a path with the same start and end point, and reviewing the measured difference in the absolute position of one sensor.

Keywords:
Motion Capturing; Inertial Sensoring; Accuracy

1 INTRODUCTION

Capturing the movements of persons can be done using different kinds of motion capturing systems. Every system has its own advantages and disadvantages. The selection of the best fitting motion capturing systems for the specific application includes aspects like range, ease of use, installation time, costs and, perhaps the most important one: accuracy.

Capturing human motion is currently often used in the movie and entertainment industry. The movements of human actors are used for controlling virtual models, to create special effects and animations in movies or games. Other industries who use motion capturing at this moment are the sport industry (for examining the movement of professional sport players), and the biomechanical industry (for determining the movements of a prosthesis).

1.1 Types of motion capturing

Capturing the motion data from objects can be done with different types of sensors and methods. The techniques can be sorted into two categories: with a line of sight (optical) and without a line of sight (non-optical).

Optical systems detect motion with the use of video cameras and with specialized software. The cameras record the setting with the moving object(s) from multiple overlapping angles. The more angles used, the more precise the motion recognition can be. The software knows exactly the position of the different cameras (the cameras should be calibrated in the room) and recognizes how the objects are moving in every camera-view. By combining this information with the information about the location of the cameras makes it possible to detect how an object moves through space. The motion of the objects are thereby calculated in relation to the room or a fixed reference point, and not linked to each other. This results in an absolute position of objects in space. There are different methods used with camera motion tracking which differ from each other by the used method of following an object. Most optical systems require a fixed spot on the body of the subject to be tracked. The spots are created by placing makers on the object. The marker with the highest accuracy is active (emitting light), followed by a less accurate passive marker (reflecting light) or capturing can be done with no marker at all (lower accuracy). The cameras follow how the markers move through space in three angles, and the software can link a body model to the movements of the markers.

In contrast to the optical tracking systems, the non-optical techniques detect motion based on the position of parts relative to each other. This means that the motion of a part is in reference to the position of the part where it's connected to. The advantage of this is that the tracked subject is not limited to a specified space. The detection of movements is done with sensors placed on the body of the subject, and wireless transmitted to a computer. Therefore there is no line of sight needed between the receiver and the tracked subject. This makes it possible to track subjects even if they are inside or behind objects. The sensors detect a 6 degree of freedom, so not only the movement of a sensor but also the rotation of it. Therefore fewer sensors are used in comparison with the markers from the optical systems.

Within this category there are multiple methods for determining the motion of a subject, the biggest difference is in the type of the used sensor. The used types of sensors are gyroscopes, magnetometers, acceleration meters and rotation sensors.

The Xsens Moven capturing system

The Xsens Moven system is a non-optical system, which uses 16 modules, each containing a gyroscope, magnetometer and acceleration sensor [2]. The system is based on inertial motion capturing. The data between the computer and the captured subject is transferred using a wireless protocol.

1.2 Accuracy

The accuracy of the systems differs a lot. Additionally, the type of accuracy is different within the system: the accuracy can be roughly separated into three categories:

- The accuracy of the position of the tracked subject in the room.
- The accuracy of the large motor skills movements like arms and legs.
- The accuracy of the movement of small motor skills like fingers.

For many companies, the accuracy of the Xsens Moven motion capturing system is a very important factor for determining if and how to use the suit. Some applications require a higher accuracy then others. In the movie and entertainment industry (being the origin of the Moven suit) the accuracy is less important than for example the ease, range and speed of use. But in other industries, like the product development sector, the accuracy can be very important for some usage scenarios.

Every motion capturing technique has its own maximum accuracy which can be achieved with the used technique. The accuracy can be negatively influenced by external factors, and measurement errors [1].

One of the goals of this case study is to determine what the expected accuracy of the Moven motion capturing is during normal use. In the case study, focus is on the overall accuracy with respect to the positioning of the captured subject in the environment. Based on the used technique in the Moven motion capturing suit, some expectations about the accuracy can be made. The measured magnetic field by the magnetic field sensors in the Moven suit can be influenced by metal or magnetic surroundings [3] [4]. This can cause miscalculations in the pose determination.

2 THE MOTION CAPTURING SUIT

The Xsens Moven suit [5] is based on miniature inertial sensors combined with biomechanical models and sensor fusion algorithms. The Moven system offers a complete wireless capture of the six degrees of body movements of a human. The data can be recorded or viewed in real-time on a desktop or laptop. The suit is made of lycra (figure 1) and has a total of 16 inertial sensors build in, which are daisy-chained connected. Each sensor module comprises 3D gyroscopes, 3D accelerometers and 3D magnetometers. All cables and sensors are embedded in the suit, and two transmitters on the back of the subject send the information to a receiver using Bluetooth.

Figure 1: The Xsens Moven suit

With the use of sensor fusion algorithms, developed by Xsens, the inertial sensors provide absolute orientation values. These are used to transform the three dimensional linear accelerations to global coordinates. These coordinates are converted into the translations of body segments. The biomechanical body model in the Moven Studio software consists of 23 segments which are connected to each other with 22 ball-socket joints (figure 2). This model includes joint constraints to eliminate drift or sliding. These constraints include the possible angles and movements a normal human joint could make. This can differ from a ball-socket joint which can move and rotate in nearly every direction, till a joint which can only provide rotation in one direction. These limitations prevent the biomechanical model to make movements or poses which are impossible for a human.

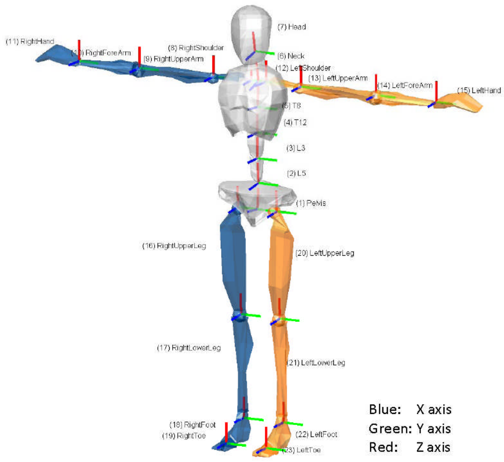

Figure 2: Biomechanical model (figure by Xsens)

The wireless range of the suit is approximately 50 metres indoor and 150 metres outdoor. Because the system has no cameras, emitters or markers, it has no occlusion or line of sight restrictions. Therefore the suit can be used in every room, or even outside, without preparing the environment. The setup phase of the suit is short; putting the suit on can be done by one person (the subject) or with a little help to speed up the process. This will take approximately 5 to 10 minutes (depending on experience of the subject). The second step is to calibrate the suit.

Calibration is required for the software to know the exact location of the sensors on the body of the subject and the current magnetic field in the room. Calibration is done by entering the body size information about the subject, like the height of different body parts, and the arm span. After entering that information it’s necessary to let the subject stand in four different poses for a short while. All this will take up to 5 minutes. When calibration is completed, the subject can move freely, and has nearly no obstruction from the suit. The suit can also be worn underneath normal clothes, if the subject feels more comfortable with that.

The Xsens Moven suit determines the pose of the body by combing the information from all sensors with a 23 segments biomechanical skeleton model of a human with 22 joints. The movement of all body-parts is related to one sensor on the pelvis. This sensor is the virtual reference sensor of the complete body movement. This means that the suit knows what the pose of the subject is, but not how that subject is positioned in the environment. The advantage with this method is that the model behaviour and visualization is not related or linked to the environment. The big disadvantage is the same: the system doesn't know where to position the model and what the interaction with the environment is.

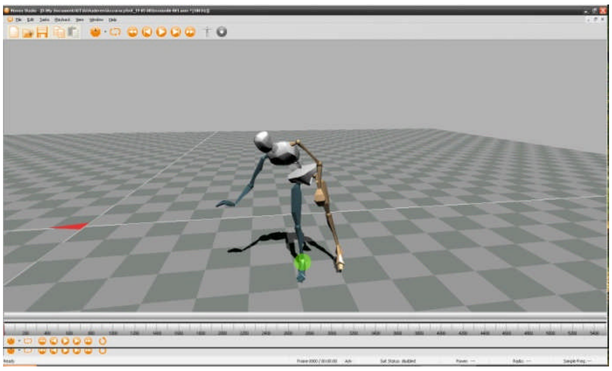

Figure 3: The Moven Studio interface

The result of this is that the suit suffers from some drift; although the subject is standing still, the complete virtual model moves slowly in the 3D environment. Here, drift is defined as an unwanted sliding movement on the horizontal plane of the complete biomechanical model in the motion capturing software. This drift is caused by small changes in the magnetic field and errors in the measurement of one or more of the sensors. The suit uses the earth's magnetic field to determine and correct the movements in the horizontal plane. But metal and magnetic objects can change this magnetic field, which causes the suit to think it's moving in a different direction. There is no drift in the vertical plane because the calculation used for determining the vertical position is not influenced by any magnetic field.

2.1 Suit-to-body inaccuracy

It can also be caused by the movement of the sensors on the body of the subject, for example if the suit is slightly moving over the skin. These small errors cause minor miscalculations, and most of the time the effect is that the whole body of the captured subject moves a bit. To test how severe this drift of the suit is in the use scenarios of this research project, the accuracy in a standard workshop room at the University of Twente with use of an Xsens Moven motion capturing suit has been tested.

3 PREPARATION

3.1 The room

The used room is not a magnetic free or completely shielded environment. The reasons for this are that i) in an unshielded room drift is minimal in case there is no magnetic disturbance and ii) the case study focuses on 'everyday' circumstances. In theory even no drift will occur if there is no disturbance measured. And because the main usage application of the suit will be in standard rooms, where always a little disturbance can occur, this will give the most reliable and useable results about the drift during most common use.

The room has a concrete floor, reinforced with steel. The floor is placed on a construction made out of metal beams. One wall is made of wood, one is made of stone and two walls are made of glass and steel. Furthermore the used area of the room was completely free of objects; except one table made of a synthetic material table-top and metal legs (see figure 4). The total size of the used room is approximately 5 by 7 metre. There were no other electronic devices powered up in the room, except the equipment used for the test and the standard available lights.

3.2 The equipment

The test is done using the Xsens Moven suit, belonging to the University of Twente. The suit was supplied with the latest available firmware (at May 2008). The data was captured on a laptop computer with a 2,00Ghz dual core processor and 2Gb of RAM. This computer was capable enough to capture the recording session at 100Hz without any delays or slow-downs. The connection was done with the standard provided Bluetooth receivers of Xsens, and the software used was Moven Studio 2.0 (figure 3). Furthermore the session was captured on video using a Sony Handycam with hard disk.

4 THE MEASUREMENT

Before every recording, a complete and successful calibration phase was done. Every session was recorded on the laptop using Motion Studio, and captured on video using the camcorder. The floor of the room was visually divided into squares of 50 by 50 centimetre. This grid was mainly used to determine the start and end point of a recording session for the captured person. A recording session consists of walking a specified pattern in the room, varying from 10 till 50 seconds (figure 4), whereby the start and endpoint are on the same location. Each pattern was first walked on slow speed, whereby at least one foot was touching the ground. Later on the speed was increased and eventually jumping and running was added to see how the suit responds when no part of the body is in contact with an object.

Although using machines/robots would render more precise results and comparison material, the test used human motion for performing the patterns. The reason for this is that on the one hand it is the best representation of the real use, but on the other hand, it can also include the problem that sensors move inside the suit or the suit moves over the body. Therefore a little measurement error can be caused by the human aspects, but these errors will also be measured in real use scenarios, and therefore should be taken into account.

Because the pattern has the same end and start point, the recording sessions on the computer should also show the character starting and ending on the same location. The video camera is only used for visual checks and documentation. If any drift occurs during the session, it will be especially visible using a top-view of the motion capturing results on the computer, and the drift will be visible by a difference in the start and end point of a test session.

Figure 4: Performing the tests

5 THE RESULTS

During the tests a total of 40 recording sessions were made. All these sessions were captured at 100 frames per second using Moven Studio 2.0. With the sessions whereby there is always contact with the ground, no post processing is used. In sessions where for some moments the ground is not touched, the motion capture is adjusted to that by post processing the result to remove ground contact during those moments. This ground contact should be removed afterwards because the Moven Studio software is processing the data that always one point of the body is touching the ground. It will adjust the model in such a way that the body part which is closest to the ground will be placed on the ground. Because that will influence the position of the biomechanical model, these contact point have to be removed afterwards. After these contact points are removed manually, the software will recalculate the model without sticking it to the ground.

To review the accuracy of the captured sessions, the 3d movement data of the suit is converted into the Biovision Hierarchy Format (.bvh). This file includes a list of the exact coordinates of each sensor 100 times per second in a readable text format. This information is filtered to only include the movements of the reference sensor on the pelvis. This is done because that sensor is in the middle of the body, and suffers the least from small pose changes in the arms and legs.

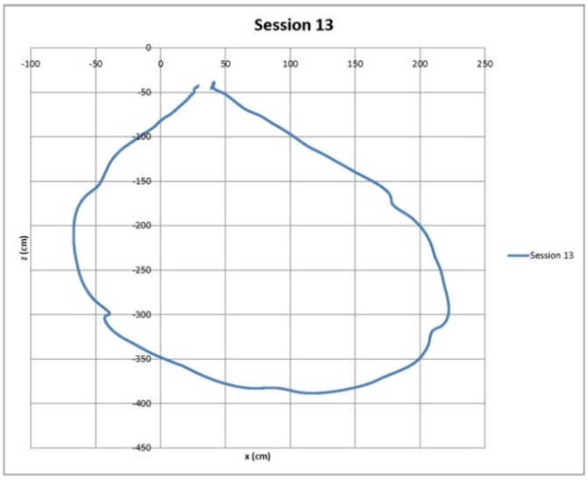

Figure 5: Result in a diagram from one test

The x, y and z movement data from that sensor is imported in a spreadsheet. The x and z movement is placed in a 'scatter diagram' to see how they move around in space. This results in a diagram (figure 5) which is in fact the top view of the location of the pelvis sensor. This diagram shows exactly how the pelvis (reference) sensor is moving in the x and z directions. The y direction (vertical movement) is not evaluated because there is no drift in that direction, due to the settings of the Moven Studio software which always place one sensor on the ground. The used coordinates from the system were reviewed with 30 frames per second. This conversion from 100 till 30 is done because the start and end point were most important, and the steps between were less important. By lowering the steps between the start and end the calculation went easier and faster, without losing important information.

In the diagrams the deviation of the suit is visible by an opening between the start and end point. The opening between the start and end point can have several causes. A part of the deviation is caused by the small difference in the pose of the user. With a human test object it's nearly impossible to let the user stand exactly on the same position and pose at the start and the end of the test. And even a small difference in the pose of the user will be visible within the results, especially when the hips are moved to the front or the back. The deviation caused by this effect can reach up to 15 centimetres. The second cause of deviation is the movement of the sensor inside the suit and over the skin of the user. The sensor is placed in the suit, which is not completely fixed to the body of the user. When the user moves, the complete suit or only a sensor can move slightly. Although this deviation will not exceed some centimetres, it's important to take it into account. The remaining part of the deviation can be ascribed to the drift of the complete motion capturing suit. This drift is a sum of all small measurement errors during the whole motion capture session.

Table 1 gives an overview about the distance between the start and end point of the reference sensors, the total distance walked in that session, the time it took and the conclusion how much the deviation is in that session indicated in the deviation per metre movement over the horizontal plane and the deviation per second of recording time. In the table 12 sessions are included; this selection from the 40 available sessions is made according to the difference of movements.

The test results show that in general slow movements cause less drift of the suit than fast movements do. Most of the small movements won't exceed a deviation of 1,8 cm per moved metre or 1,6 cm per second of recording. An exception to this is session 17, whereby the movements were slow, but the drift is more than double than other slow movement sessions. This can be caused by the larger steps made during that session. Especially the steps of 100 cm can cause that the feet are standing still for a long time, while the rest of the body is moving. That this aspect can cause drift is visible in session 26; although there was nearly no movement during that session, an enormous drift occurred. This means that when standing still, the suit starts to drift more than while moving slowly. A reason for this can be that in the calculation of the suit errors of the measurements are corrected by comparing them with the movement of other sensors. When all sensors are standing still (or at least the sensors which touch the ground) it's more difficult to filter the real movement data from the error data. These kinds of effects can be decreased by post-processing the results, and locking the position of the feet sensors when they touch the ground. This requires more work afterwards, but increases the accuracy. Unfortunately this can't be used in real-time recording.

Another aspect which causes drift is when the user is not in contact with the ground, for example while jumping. The suit has no reference to a fixed position at that moment, and can therefore make fewer corrections for filtering out errors. Another cause of jumping is that the suit and sensors have a bigger change of moving over the body of the subject. The shock of the body when it lands can cause the sensors to move, or to measure enormous peaks in the movement.

In general the conclusion is that how faster, less in touch with the ground and longer lasting the movements are, the more drift will occur.

	Description	Δt_{start}-t_{end} (cm)	Total distance (cm)	Total time (s)	Deviation/m (cm)	Deviation/s (cm)
04	Slow walk in line	16,56	1088	10,33	1,522	1,602
06	Slow walk in line 2x	58,15	3387	48,33	1,717	1,203
08	Slow random walk	38,54	2123	26,67	1,815	1,445
13	Fast walk in circle	10,46	983	10,33	1,064	1,013
14	Fast walk in line 2x	52,64	2114	12,67	2,490	4,156
16	Slow shuffle left-right and walk	31,13	3562	42,17	0,874	0,738
17	Slow steps of 50cm and 100cm 2x	79,74	2422	27,90	3,293	2,858
24	Fast shuffle left-right and walk	109,33	2662	25,50	4,107	4,287
26	Standing still for long time	68,12	939	37,00	7,258	1,841
29	Long combination of fast running and walking	162,13	10319	91,00	1,571	1,782
32	Run a line several times	48,17	3658	28,23	1,317	1,706
36	Jump in a line, less floor contact	221,52	3035	23,67	7,298	9,360
				Average:	**2,860**	**2,666**

Table 1: Results from 12 test sessions

6 MINIMIZING OR PREVENTING THE DRIFT

There are multiple options for minimizing or preventing the drift of the Xsens Moven suit. The whole problem is caused by the magnetic field sensors which are integrated in each sensor module. The best solution would be to find a replacement technique for determining the orientation in the horizontal plane, without using the earth's magnetic field. This can be an external system which will determine the absolute position of the sensors in space. An optical motion tracking or local position system, which refers to a fixed object in the room, could be used. The disadvantage of that solution is that those techniques limit the area of use and will increase the setup time of the motion capturing system.

Another option is to minimize the drift by performing small calibrations during the use of the suit. This can be done for example by placing a sensor module on a predefined place in the environment, whereby the software can compare the measured position to the real position of the sensor module, and adjust the values according to that. If the user is interacting with an object which is also available in the virtual environment, a quick calibration can be made by using pressure sensors on the contact point of the body (hand, feet, back, and bottom). If a pressure sensor recognizes contact with an object, the software can review if the virtual model is also in contact with an object. If not, an error is measured and the software should compensate that. This means that the complete real environment of the recording session must be available in the virtual environment of the model.

7 CONCLUSION

One of the major problems of an inertial motion capturing system is the drift on the horizontal plane. During the test session drift was encountered especially on moments when there was no contact with the ground, or by fast movements like running. This means that the drift should be taken into account nearly all the time. During slow and small movements the drift is less, but the movement of the body is also less. Therefore the relative measured error is in line with the made movements.

This drift can be a problem in scenarios where the position of the user in the room very important. In those usage scenarios an additional motion capturing or location determination technique should be added to the Xsens Moven suit the make it useful. In situations where the pose of the captured person is the most important data needed, the location of the captured subject can be less useful, and in those kinds of situations the Xsens Moven suit can be a useful tool.

8 REFERENCES

[1] Luinge, H.J., 2002, PhD Thesis, 'Inertial Sensing of Human Movement', University of Twente, The Netherlands

[2] Roetenberg, D., Luinge, H., Slycke, P., 2008, 'Moven: Full 6DOF Human Motion Tracking Using Miniature Inertial Sensors'

[3] Roetenberg, D., 2006, PhD Thesis, 'Inertial and Magnetic Sensing of Human Motion', University of Twente, The Netherlands

[4] O'Brien, J.F., Bodenheimer Jr., E., Brostow, G.J., Hodgins, J.K., 2000, 'Automatic Joint Parameter Estimation from Magnetic Motion Capture Data'

[5] Xsens Technologies, http://www.xsens.com