Human Motion Regeneration using Sensors and Vision

S. M. N. Arosha Senanayake,
School of Engineering
Monash University Sunway Campus
Bandar Sunway, Malaysia
Senanayake.namal@eng.monash.edu.my

Alpha Agape Gopalai
School of Engineering
Monash University Sunway Campus
Bandar Sunway, Malaysia

Abstract— **This paper explores the opportunity of using tri-axial wireless accelerometers and optical camera system for human motion regeneration. A motion analysis system based on stick figures and musculoskeletal model is developed. Accelerometers are placed on joints of human body and markers are placed on the similar joints for the vision system. Data are acquired from these sensors in soft-real time using virtual instrumentation; the acquired data is then conditioned and converted into required parameters for motion regeneration. In vision based data acquiring is based on Motion Capture (MOCAP) data which is required during both the modeling and simulation process of the musculoskeletal models. While sensor based motion regeneration in this paper deals with the motion of the human body segment in the X and Y direction, looking into the motion of the anterior/ posterior and lateral directions respectively, vision based motion regeneration addresses three dimensional full body musculoskeletal model. In order to regenerate specific human motion, lawn bowling action and soccer actions have been selected during the simulation.**

Keywords—**stick figure animation, Motion Capture Data, Musculoskeletel model, soft-real time**

I. INTRODUCTION

Motion capture technologies work by tracking the positions and orientations of sensors, which have been strategically placed on human body, over time. There are several types of sensory devices that can be used to capture this information, however the predominate technologies of modern motion capturing fall into three categories: optical, magnetic or mechanical.

Optical capture devices track the motion of the human through the use of small markers that are attached to the body, which reflect back infrared light that is emitted and captured by high-resolution cameras. Given the camera inputs, it is then the job of the capture software to triangulate the markers in space and produce a data stream of positional coordinates for each marker.

In the case of magnetic devices, the sensors used are sensitive to polarised electromagnetic fields that are emitted from a central transmitter. When the sensor readings are conveyed back to the software, they are converted into location and orientation metrics, however this requires a degree of cabling to connect the sensors to the computer. This is achieved by threading the individual sensor cables into a special suit which are centrally collated, usually worn by the human, and transferred to a computer through either a central cable or wireless technology.

Unlike both optical and magnetic devices that rely on an emission and detection process, mechanical capture devices measure angular and positional differences between mechanically connected points. This is accomplished using a system of styluses that are fixed at specific locations on the human body.

In this research, tri-axial wireless accelerometers and optical capture devices are chosen to regenerate human motion.

Tri-axial accelerometers provide information on the acceleration in three planes, namely the vertical plane (Z-axis), anterior and posterior (Y-axis) and lateral direction (X-axis). The need for a system that is capable of acquiring and processing data in real time is clear. A soft real time system is a system that would still be able to perform, with minor degradation, if deadlines are not met. The type of system that a human motion analysis system would require, in the interest of cost and complexity, is ideally a soft real time system. Current available systems for accelerometry systems are restrictive when applying the system in real time. Outputs from these available systems are still in the raw accelerometer's data format – 'accelerobits'. Data conversion within the existing system is impossible and has to be done separately (post-processing) which puts a heavy time requirement tag on the system [1].

The accelerometry system developed for human motion regeneration in this paper is capable of retrieving data from the accelerometers in real time (soft real time) using virtual instrumentation techniques. These acquired data is then conditioned and processed with a relatively small and constant time requirement, within a single platform. Making the processed data available in the shortest possible time is essential in this application for the end user, to provide effective and meaningful feedback. Due to the nature of the end user, an interface that is capable of facilitating all wireless commands broadcast and data acquisition is required. This interface is to be simple and straight forward, which allows end user some level of freedom to set data-logging parameters and to view graphical representation of acquired data, as well as the stick figures displaying the regenerated figure.

When it comes to optical capture devices, Motion Capture (MOCAP) data must be acquired first. MOCAP data is required during both the modeling and simulation process of the musculoskeletal models. During the modeling process, the

MOCAP data are used to give the musculoskeletal model an initial pose or stance, while the simulation process requires MOCAP data to move or animate the musculoskeletal model.

II. MOTION REGENRATION USING SENSORS

A. *Wireless Sensors used and its charateristics*

The device used to collect gait/motion data for the analysis methods consists of a G – Link tri-axial wireless accelerometer 5/10g that consists of 3 ADXL 210E accelerometers, which gives the unit 3 measuring axes. It is compact in size (25mm x 25mm x 5mm) which makes it possible for placement at critical points of interest on the subjects body without obstructing the natural motion of the subject, 2 MB of on board memory storage (stores up to 1 million data points), low power requirement – 9 Volt.

The accelerometers were placed on the test subject's body at points of interest, to measure the acceleration at that point; the accelerometers were strapped down to the test subject's body using elastic body straps. The accelerometers has to be securely strapped down to the test subject's body to ensure that the measurement obtained is purely due to the movement of the test subject and not due to the movement of the accelerometers within the body straps (noise).

The wireless sensors' establishes communication with a PC via a USB base station using radio frequency of 900 MHz as its communication medium. The USB base station attached to a computer enables end user to issue various commands to the accelerometers via the USB base station.

A PC based accelerometry system was developed to obtain human motion (gait) data in real time from accelerometers that are physically attached to a test subject's body. Accelerometers communicate via Radio Frequency (RF) to the PC [2]. Data obtained from accelerometers is then conditioned and converted into appropriate kinematical parameters and outputs, which then are displayed in a graphical form for ease of interpretation (numerical also available), the key feature in the designed system is, the systems runs on a single programming platform from the initial processes, data acquisition, to the its final processes if data interpretation.

The designed system will also be capable of performing two dimensional motion regeneration of the test subject on the similar programming platform. Motion of the subject will be recorded during the data logging session and plotted/ re-constructed in real time. The reason motion reconstruction is included as a feature of the system, is to enable the end user to make a better judgment/ observation on the motion of the test subject and to provide immediate and effective feedback to the subject if the end user may have detected a flaw in the motion or position of the test subject's body segments.

B. *Lawn Bowler in Stick Figure*

In order to display the results acquired from the accelerometer in terms of a regenerated motion, a stick figure is designed to function with the accelerometer control system. A stick figure is a simple type of drawing to depict the general form of humans. For this paper, a human stick figure is designed for displaying results of motion regeneration.

All tests that have been done have shown that the tip of the right foot does not move from its position, therefore all calculations for positions will start from the tips of the right foot.

The ratio of the length of the body must also be considered in the development of the stick figure program. Most drawings of the human body take the length of the head as the reference for calculating lengths of different parts of the body, figure 1.

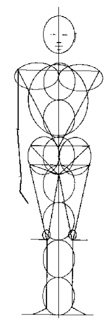

Figure 1: Body Segment Lengths with Reference to the Head

The average length for the head is assumed to be 230 mm. From the diagram above, the length of the body parts can be summarized in the table 1.

TABLE 1: LENGTH OF BODY SEGMENTS

Body Part	Node	Length
Foot	14	Graphical length = 100mm
Shins	15 & 17	2 heads = 230 * 2 = 460mm
Thighs	91 & 92	2 heads = 230 * 2 = 460mm
Chest	20	2 heads = 230 * 2 = 460mm
Upper Arm	87 & 88	1 head = 230 mm
Lower Arm	89 & 90	1 head = 230 mm
Palm	94	Graphical length = 70 mm

Readings obtain from the accelerometers are in terms of acceleration. In order to plot the position of each segment the displacement is required. In this paper, a very simple numerical analysis method is employed to convert acceleration to displacement, using the trapezoidal rule by means of double integration.

III. MOTION REGENARTION USING OPTICAL CAPTURE DEVICES

The MOCAP system that was used is the Motion Analysis Corporation (MAC) MOCAP system. The test subjects were required to wear non-reflective body suits which are basically scuba diving suits while also removing any reflective material that will affect the motion capture process. After fitting into the non-reflective suit, 39 markers are attached to relevant points on the body of the test subject. The marker placement follows a standard marker protocol known as the plug-in marker gait, which is used worldwide for MOCAP applications. Besides that, in order to facilitate an easier process for placing markers on the foot of the test subject, the foot markers are pasted on shoes with different sizes as different test subjects have different foot sizes [3].

After having selected a modeling and simulation tool (LifeMOD) and after successfully converting the MOCAP data, the next step is to model the musculoskeletal models of each test subject. The modeling of each test subject's musculoskeletal model involves a set of processes; *body segment generation, Joint/soft tissues (muscle) creation, MOCAP data import and contact creation*.

A. *Musculoskeltel Model Creation*

There are three different ways to generate the musculoskeletal model. LifeMOD offers a standard anthropometric body sizes for people who are living in the UK, USA, China and Japan. This database is known as the People Size Anthropometric Database and human skeletal segments can be generated based on this particular database. The second method to generate the skeletal segments of the human body is by reading from a SLF text file format which has the measurement of the human segments recorded. The final method of generating the musculoskeletal model of the subject is to specify simple description of the subject such as the gender, age, weight and height. This method can be used by selecting the GeBOD Anthropometric Database option under the Anthropometric Database field. For this project, the GeBOD Anthropometric Database is selected because it offers the user to key in main features of the human characteristics such as the age and gender and it also allows the user to modify the segment lengths later if it is found that the initial values are inaccurate. Besides that, the subjects that will be tested are mostly from Malaysia; hence the People Size Anthropometric Database is not suitable for the context of this project [4].

There are three methods to prepare the joints in the musculoskeletal model. The user can choose between Hybrid III Crash Dummy Strength Elements joints, Trainable Passive Elements Joints or generate joints based on SLF file format. For each of these methods, the individual joints can be edited if the user is not satisfied with the joint relationship or finds that the joint definition is not correctly defined. The joint groupings for all three methods are based on the spine, arms and legs. For this project, the method for preparing the joints with "TRAINABLE" passive elements is chosen because the other two methods are not relevant or applicable in the context of this project. The analysis for this project is based on real test subjects and these test subjects are not crash dummies hence the method for preparing joints associated with Crash Dummy is not selected. The preparation of joints via SLF file has not been selected because there is insufficient data and the best option is to use the joints with trainable passive elements.

After the creation of joints and soft tissues, the next step is to import the MOCAP data which has been converted into the .SLF format to give an initial pose to the musculoskeletal model. Before proceeding to the next section, Figure 2 and 3 show the joints and soft tissues created in the musculoskeletal model. In Figure 2, the light blue bubbles are representation of the joints while the red stripes found in the musculoskeletal model of Figure 3 denote the muscles or soft-tissues created.

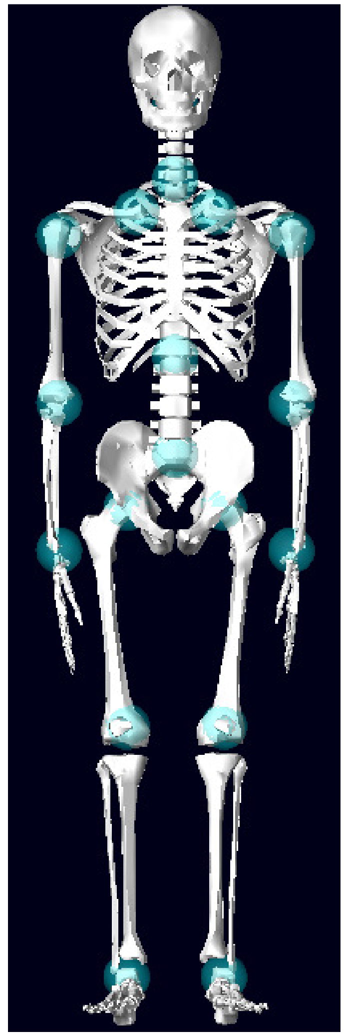

Figure2: Musculoskeletal model with joints

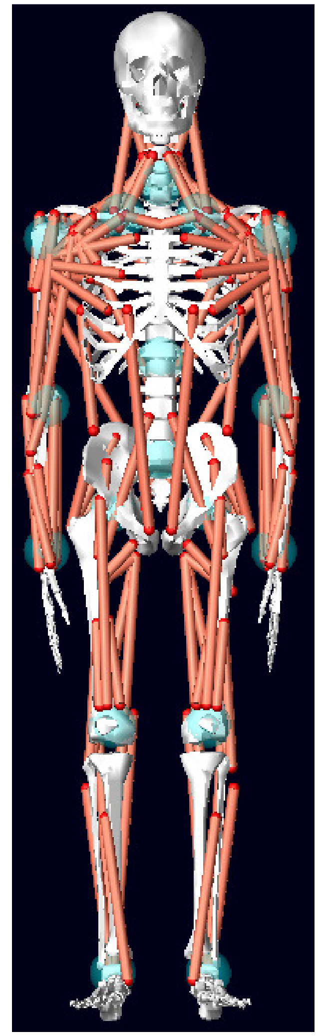

Figure 3: Musculoskeletal with joints and muscles

After generating the musculoskeletal model and holding the skeleton together with the creation of joints and muscles, an initial pose or position needs to be defined in the modeling process. As can be seen from Figure 2 and 3, the generated musculoskeletal model is at a standstill position, thus, the MOCAP data's purpose is to give an initial pose or starting position to the musculoskeletal model. In order to achieve that, MOCAP data needs to be imported. The start and end time can be specified. This means that the MOCAP data may range from 0 – 8 seconds, however the simulation can be specified to start from 4 seconds and ends at 7.5 seconds. After setting all the parameters, the next step is to create a base set of motion agents. The motion agents are the standard set of marker protocols and the panel for creating the motion agent [5], [6], [7], [8], [9].

MOCAP data points as a time interval will be specified to move the model to the starting point. At the modeling stage, the interest is only to assign a starting position to the musculoskeletal model and not to animate it. The animation of the musculoskeletal will be done in the simulation stage. If the "Freeze Motion Agents for Equilibrium Analysis" option is unchecked, the yellow spheres will follow their own MOCAP data point trajectory and the initial position will be lost. After the yellow and red spheres are very close together, which means the musculoskeletal model has moved into the starting position, the posture can be updated by pressing the "Update Model Posture with Equilibrium Results". Once this is pressed, the posture of the musculoskeletal is fixed [10], [11].

Once the posture has been updated, the musculoskeletal model will stay at that position. The musculoskeletal model with an updated posture is as shown in Figure 4.

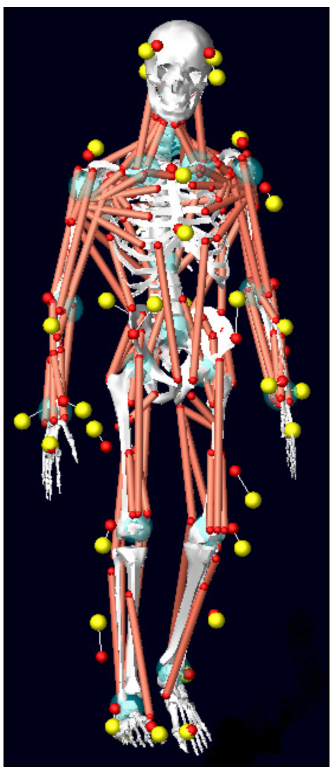

Figure 4: Updated Posture of the musculoskeletal model

After successfully updating the model's posture, the next step in the modeling process is to create the necessary contacts between the musculoskeletal model and the environment.

Contact forces between the body segments and the environment or objects are created using ellipsoid-plate contact elements or the solid-solid contact algorithm which are provided by LifeMOD. The contacts created for this project is to create contacts between the foot of the musculoskeletal model and the soccer pitch or floor. The contact stiffness, damping, friction and other parameters can be set to specify the type of contact that is encountered by the musculoskeletal model. The contact surface which is the soccer pitch can be generated by specifying the length, width as well as its thickness. After the contacts have been created between the musculoskeletal model and the soccer pitch, there will be arrows and wordings near the area of contacts as can be seen in Figure 5.

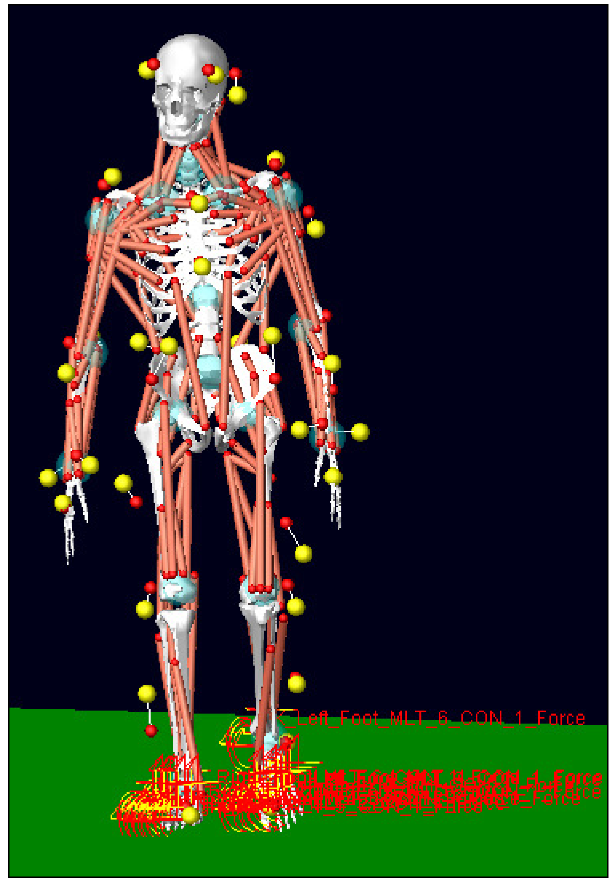

Figure 5: Musculoskeletal model with created contacts

IV. SIMULATION

After having modeled stick figures based on wireless sensors and musculoskeletal model based on optical capture devices, human models are in position to carry out different human movements. While human stick figure simulates lawn bowler, musculoskeletal model simulates soccer player in order to demonstrate different human motion regeneration is possible [12], [13], [14], [15].

A. *Human Stick Figure Simulation in Lawn Bowling*

Simulation in lawn bowling is based on all derived parameters displacements, velocities and angles between joints. These parameters are obtained taking into consideration specific gait cycle from each of the resultant acceleration graphs already given figure 6 and the rest of motions from all other sensors. LabVIEW is used to regenerate the motion of lawn bowling.

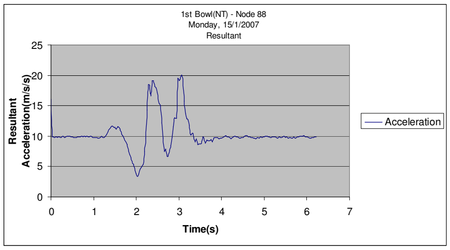

Figure 6. Resultant acceleration of wrist in lawn bowling

In order to visualize graphically, discrete time intervals are defined such a way that lawn bowling actions are correctly displayed during the simulation as shown in figures 7 and 8.

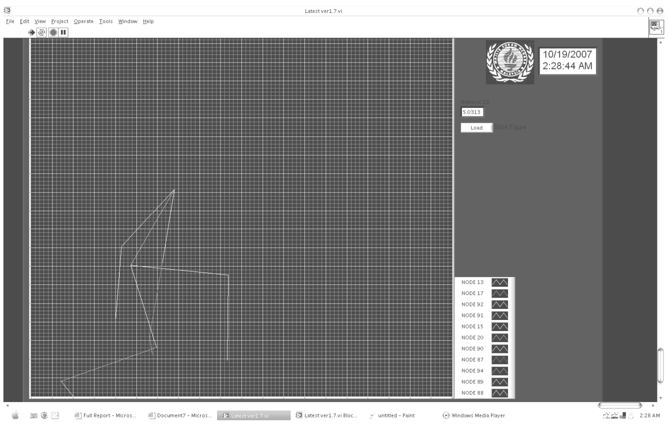

Figure 7. Lawn Bowler before releasing the ball

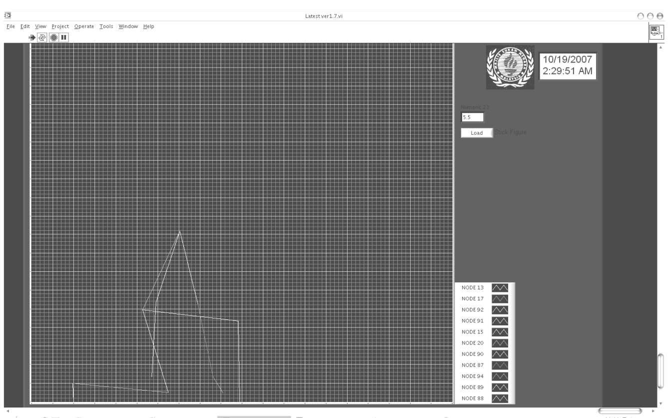

Figure 8. Lawn Bowler about to release the ball

B. *Musculoskeletal Model Simulation in Soccer*

After the musculoskeletal modeling process using MOCAP data has been completed, the simulation process may begin and the simulation procedure can be summarized into two steps which are; Inverse Dynamics Simulation, Forward Dynamics Simulation [6], [7], [8].

Before the inverse dynamics simulation is performed, the red and yellow spheres' location needs to be synchronized. This is to because during the inverse dynamics simulation, the musculoskeletal model is driven by the MOCAP data through the movement of the motion agents. Hence, the motion agents need to be at body marker location to move the musculoskeletal model in the correct manner. At this stage, the joints and muscles created will learn and capture the joint angulations and the shortening or lengthening patterns respectively. The joints and muscles are 'learning' the patterns because during the joints and soft tissues step, these elements are set to "TRAINABLE". Thus, the inverse dynamics simulation is actually training the joints and muscles of the musculoskeletal model.

The forward dynamics simulation is performed only after the inverse dynamics simulation has been successfully completed. During the forward dynamics simulation, the motion agents are 'disabled' meaning that they are no longer driving the musculoskeletal model. The movement of the musculoskeletal model during this stage is generated by the joints and muscles which has stored the joint angulation and muscle shortening and lengthening patterns from the inverse dynamics simulation. The musculoskeletal model will be driven by the joint torques and muscle forces while under the influence of other external forces such as gravity and the contact between the foot and the soccer pitch. However, before actually performing the forward dynamics simulation, the TRAINED joints and muscles needs to be 'installed' onto the musculoskeletal model. If the trained joints and muscles are not installed, it will continue to learn even during the forward dynamics simulation. Hence, it is essential that the trained joints and muscles are installed for accurate simulation results. After the trained joints are installed, there is a noticeable change of appearance at the joints. The trained joints have a dark blue colour as compared to the TRAINABLE joints which are light blue in colour.

After the forward dynamics simulation has been completed, the software has a list of results that can be generated. The results range from kinematics to kinetics data. The results obtained from the simulation will be analyzed and then useful information will be extracted. The results that were taken resulting from the simulation are the joint angle plot in various planes (Sagittal, Frontal and Transverse plane) for the lower extremity of the body which includes the hip, knee, and ankle joint. A sample of the result is shown in Figure 9.

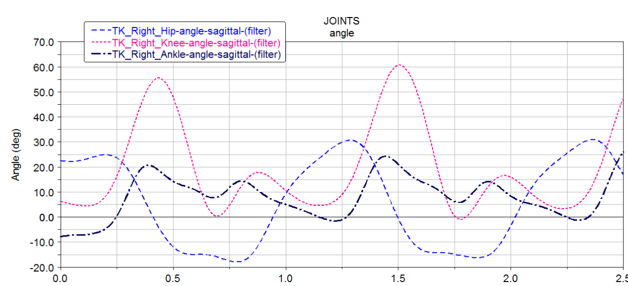

Figure 9: Hip, Knee and Ankle angle in the Sagittal Plane during Walking

After the forward dynamics simulation has been performed, the results window also includes the option to export the video of the simulation. This video was saved for all the actions that were performed by all the test subjects so as to facilitate this stage of feature extraction. In the recorded video, there is a display showing the time as well as the number of frames that is progressing as the video is playing as highlighted in a red bounding box in Figure 10. Hence, this information is used to determine the start and end of one gait cycle for a specific motion. This process is done manually as each test subject has different gait cycle time. An example of specifying the gait cycle time for a walking motion is depicted in Figure 11.

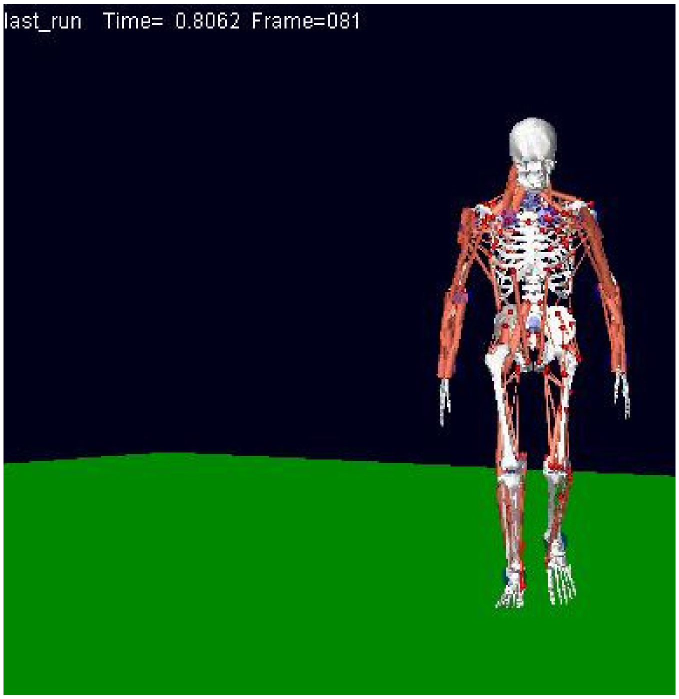

Figure 10: Video showing number of frames and time elapsed

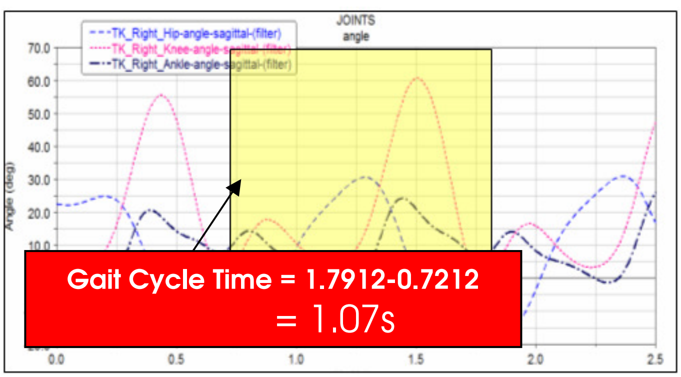

Figure 11: Specifying the Gait Cycle Time

ACKNOWLEDGMENT

Authors appreciate particularly Dr. Barry D. Wilson, Senior Biomechanics Consultant, National Sports Institute, Malaysia for his valuable discussions and the facilities, especially optical captures devices provided from the National Sports Institute to conduct this research.

REFERENCES

[1] Merryn J Mathie, Adelle C F Coster, Nigel H Lovell and Branko G Celler, "Accelerometry: providing an integrated, practical method for long-term, ambulatory monitoring of human movement", *2004 Physiol. Meas.* ***25*** *R1-R20 doi:10.1088/0967-3334/25/2/R01*.

[2] A. A. Gopalai and S.M.N.A Senanayake, "Real Time Instrumented System for Gait Analysis" Computer, Communication and Control Technologies (CCCT), Orlando, Florida, 2007.

[3] Novacheck, T. F. , "The Biomechanics of Running", Gait and Posture 7, pp 77-95, 1998.

[4] Edmund Chao, Y.S., Graphic-based musculoskeletal model for biomechanical analyses and animation Medical Engineering & Physics 25, pp. 201-212, 2003.

[5] Kibele A. "Possibilities and limitations in the biomechanical analysis of countermovement jumps: A methodological study" J. Appl. Biomech , Vol 14, pp. 105–117, 1998.

[6] B. H. Khoo, S. M. N. A. Senanayake, D. Gouwanda and B. Wilson, "A portable vertical jump analysis", *The Impact of Technologies on Sports*, 2007, Taylor & Francis Group, London, pp. 637-642

[7] D. Gouwanda and S. M. N. A. Senanayake, "Instrumented Multilayer Sensorized Floor for Sports", Proc. 5th International Conference on Computing, Communications and Control Technologies (CCCT), 2007

[8] S. M. N. A. Senanayake, D. Looi, M. Liew, K. Wong and J. W. Hee, "Smart Floor Design for Human Gait Analysis" *The Impact of Technologies on Sports*, 2007, Taylor & Francis Group, London, pp. 189-192

[9] A.A. Bakar, and S. M. N. A. Senanayake, "Intelligent System for Soccer Gait Pattern Recognition", *The Impact of Technologies on Sports*, 2007, Taylor & Francis Group, London, pp. 415-420

[10] A.A. Bakar, S. M. N. A. Senanayake, R. Ganason and B.D. Wilson, "Pattern Recognition in Gait Analysis", *The Impact of Technologies on Sports*, 2007, Taylor & Francis Group, London, pp. 169-174

[11] S. M. N. A. Senanayake and T. K. Khoo, "Intelligent Musculosoccer Simulator", *The Impact of Technologies on Sports*, 2007, Taylor & Francis Group, London, pp. 409-414

[12] S. M. N. A. Senanayake, A. W. Y. Wong, and B. D. Wilson, " Accelerometry in Motion Analysis", *The Impact of Technologies on Sports*, 2007, Taylor & Francis Group, London, pp. 474-484

[13] S. M. N. A. Senanayake and A. A. Gopalai, "Real Time Instrumented System for Gait Analysis", *Proc. 5th International Conference on Computing, Communications and Control Technologies (CCCT),* 2007

[14] S. M. N. A. Senanayake and Y. Z. Chong, "Intelligent System for Soccer Gait" *International Conference on Automation Science and Engineering*, Shanghai, 2006 pp. 204-209

[15] S. M. N. A. Senanayake and Y. Z. Chong, "Analysis of Soccer Actions Using Wireless Accelerometers", *The 4th International Conference in Industrial Informatics*, Singapore, 2006, pp. 664-669