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Human Motion Regeneration in 2-Dimension as Stick Figure Animation with Accelerometers

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***Abstract*—**This paper explores the opportunity of using tri-axial wireless accelerometers for supervised monitoring of sports movements. A motion analysis system for the upper extremities of lawn bowlers in particular is developed. Accelerometers are placed on parts of human body such as the chest to represent the shoulder movements, the back to capture the trunk motion, back of the hand, the wrist and one above the elbow, to capture arm movements. These sensors placement are carefully designed in order to avoid restricting bowler's movements. Data is 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. A user interface was also created to facilitate in the acquisition of data, and broadcasting of commands to the wireless accelerometers. All 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.

***Keywords*—**Motion Regeneration, Virtual Instrumentation, Wireless Accelerometers

I. Introduction

THERE are many viewpoints from which we can observe a certain gait such as the side view, front view, and the back view. How do we determine the best view point to observe the gait or motion of a subject? The views obtained at all this viewpoints may seem similar to one who is not a trained observer in bio-mechanics, if careful attention has been made to the selection of viewpoint one would be able to identify the difference in forms displayed by an elite hurdler, for instance, and a novice hurdler or in the functioning of a normal knee and an injured/ partially rehabilitated knee.

The process of analyzing the gait of subject to this extends is often referred to as Motion Analysis. Motion analysis is the detailed study of human motion, in a certain task or within a certain area. Common available methods for motion analysis are mostly depended on vision systems [1], although the vision system is a common approach, it poses some major limitation. This would be discussed in detail in the later part of this paper (Section II). The work done in this paper uses the sensor based approach to perform motion analysis. We used a single type of sensor for this purpose – a tri- axial accelerometer.

Motion analysis is very important for sports performance enhancement and injury prevention [1]. Accelerometer has been proven to be a very useful for short term supervised monitoring and long term unsupervised monitoring [2]. Accelerometers have the advantage being resilient and robust in trying conditions, which makes it ideal to perform motion analysis on different types of sports [3]. The motion analysis developed in this work, deals only with a 2 dimensional motion analysis, along the mid-sagittal plane.

A system that is capable of acquiring and processing data in soft real time was designed to facilitate in the data acquisition process [3]. A soft real time system is a system that would still be able to perform, with minor degradation, if deadlines are not met. A typical human motion analysis system would require a soft real time system, in the interest of cost and complexity. The main requirement for a motion analysis system is the capability of a system to provide the required data at the required time, which is often shortly after a sample has been recorded/ collected, without the need for long post-processing. Current available systems for accelerometry systems are restrictive, outputs from available systems are still in the raw accelerometer's data format. Data conversion/ interpretation within the existing system are impossible/ limited and have to be done separately (post-processing) which puts a heavy time requirement tag on the system.

The result from the motion analysis is used to perform motion regeneration in a 2 dimensional plot. Motion regeneration in its simplest definition is the ability of a model (hardware/ software) to mimic a certain motion previously done with high repeatability. In the scope of this work a 2 dimensional stick figure (model) would be used to regenerate the motion of a lawn bowler, with the aids of the physically attached accelerometers on the body segments of the lawn bowler.

The application of motion analysis is not only limited to sporting field. Motion analysis can be used in injury prevention – of the young and old, rehabilitation – of the injured and temporarily disabled, and prosthetics – helps designers understand natural human limb functionality.

II. Vision Versus Sensor Approach

Vision systems are excellent when it comes to non-ambulatory data acquisition of a certain motion. Data

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collection methods are non-obstrutive; hence data collection can be done independent of the test subject [1].

As promising as it may sound, the vision system does pose some major drawbacks that is still unsolvable at this point in time. A common problem that a vision system faces is the robustness of the system, a vision system would be susceptible and vulnerable to the environment in which the system is to be placed [4]. A vision system may not adjust and accommodate easily to major changes made in the environment or lighting condition of the area. These changes may result in erroneous and misleading data sets. Vision systems are excellent solution if data is to be acquired in a controlled environment, where users have full control over all elements in the environment.

When it comes to measuring the joint angles and joint kinematics, vision system relies on the efficiency of the algorithm employed to determine the 'estimate' location of a joint, before it can determine the position of a segment relative to the its adjacent segment, from which the joint angles and joint kinematics is derived [4]. This estimation tends to be a rough estimate as the origin of a joint is estimated based skin surface, regardless if the area was automatically selected using an algorithm or if it was manually selected by the end user.

This matter is easily solved when using a sensor based approach, as we are in total control of the exact location at which we choose to physically attach the sensors to the human segments. With prior knowledge of the location of the sensors, we can perform inverse kinematics and required transformations to arrive at the joint angles and joint kinematics, which would be more accurate then the estimate parameters obtained using the vision approach.

On a lighter note, vision system often times require a calibration process where the image captured has to be calibrated, to ensure accurate position data. This calibration routine has to be conducted each time there is a significant change in the environment [4].

The sensor approach provides an ambulatory data acquisition and motion analysis solution [5]. It is not vulnerable and susceptible to environment changes as the vision system is. It also does not need to be repeatedly calibrated to ensure data accuracy. However, the sensor approach being an ambulatory approach requires for sensors to be physically attached/ placed on the subjects' body segments. The placement of these sensors limits the range/ radius in which the subject can move about in, if reliable real time data streaming is required.

Another aspect that has to be looked into is the physical size and weight of the sensor (accelerometer) that is to be attached to the human segment. Introducing a sensor with large dimensions and a high mass would, impose some form of restriction to the natural motion and the flow of motion of the test subject [5]. This would defeat the entire purpose of motion analysis.

Due to its ambulatory nature of data acquisition, a sensor (accelerometer) approach to motion analysis, can only be done when a subject/ athlete is in rehabilitation/ training [3]. Where coaches can study the interpreted sensor feedback and provide constructive feedback to players. The work done in this paper is done to compliment coaches' effort during the training session of a lawn bowler. Detailed explanation of the sensor used is described in the following section.

III. System Requirement & Capabilities

The basic requirement of the system is for real time (soft) data acquisition. The acquired data should be processed and interpreted for the ease of the end user. A graphical representation of the data set is also required, to help facilitate the end user in monitoring gait patterns of the test subject.

A PC based accelerometry system was developed to obtain human motion (gait) data in real time from accelerometers that were physically attached to the test subjects' body. Accelerometers communicate via Radio Frequency (RF) to the PC at a bandwidth of 900MHz. 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 (also available in numerical values if required). The key feature in the designed system is, the systems runs on a single programming platform from the initial processes of data acquisition, to its final processes of data interpretation and motion regeneration.

The designed system is capable of performing a 2 dimensional motion regeneration of the test subjects'. Motion of the subject will be recorded/ acquired 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 detected a flaw in the motion or position of the test subject's body segments [10].

Motion regeneration also allows for the captured/ recorded motion to be reviewed again, at a certain point of time in the future, where coaches can monitor different styles and methods that players apply during their game/ training session.

In lawn bowling a 2 dimensional motion regeneration would suffice as most of the body segments of the player/ bowler that are involve to make a good bowl, are motions on the sagittal plane. These motions will be covered in detail in the following sections [9]. A 3 dimensional motion regeneration system may be proof to be useful as the stability of segments on the frontal plane will be made available. However, this option is made unavailable due to the limitations imposed by the sensors, as discussed in the next section.

In general, the system designed here, should consist of an interface that facilitates with the acquisition of data in real-time. The system then carries out the necessary processes in the background to interpret the acquired data to useful kinematical data, which will be presented to the end user, and used for regenerating the captured motion. All of this will be done in a soft real time environment, to ensure that the data is presented to the end user, in a timely manner. Data which is presented in an untimely manner carries no weight and meaning for the end user, it then becomes useless regardless of how valuable the data may have been [10].

IV. Hardware Description

The device used to collect gait/motion data for the analysis methods consists of a G – Link tri-axial wireless accelerometer that is capable of measuring up to 10g that consists of 3 measuring axes (g here is with reference to the gravitational acceleration – 9.81m/s2). 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 flow of the subjects' motion, and is capable of storing up to 2 MB of onboard memory (stores up to 1 million data points), low power requirement – 9 Volt.

The accelerometers were physically placed on the test subject's body at points of interest (Fig. 1), to measure the acceleration at that point; the accelerometers were strapped down to the test subject's body using elastic sporting straps. The accelerometers has to be securely strapped down to the subjects' body to ensure that the measurement obtained is purely due to the subjects' motion and not due to the vibration of the accelerometers within the body straps (noise) as was pointed out in [6] and [7]. Fig. 2 shows the measuring axes of the accelerometers.

The wireless sensors' establishes communication with a PC via a USB base station, Fig. 3, using radio frequency at a bandwidth 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.

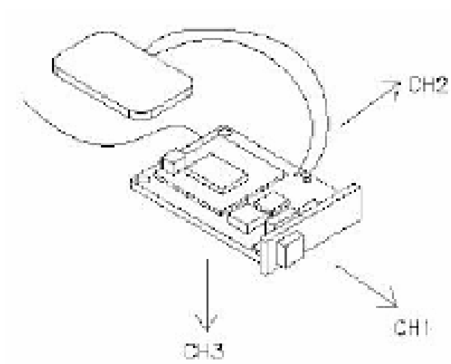

Fig. 1 The Triaxial Accelerometer

It is important to know the basic operational concept of the accelerometers. The accelerometer measures the acceleration by determining the gravity vector in the Earth Coordinate frame, hence the acceleration measured is always relative to the previous frame [8]. Determination of the relationship of the measurement in the sensor coordinate frame to the gravity vector allows for the estimation of orientation and distance travelled relative to the horizontal plane. The accelerometers would not be able to determine any form of changes when there is a vertical rotation, as the projection of the gravity vector acting on the principal axis would not change.

In this paper, motion regeneration is performed using the estimation of distance by means of numerical analysis from the measured acceleration values. An alternative method is also discussed in this paper, where motion regeneration is achieved by means of determining the orientation of each segment – both methods involves the motion regeneration in a 2 dimensional space.

Other hardware involved for this work is a standard desktop on which data is stored, processed, forward and saved.

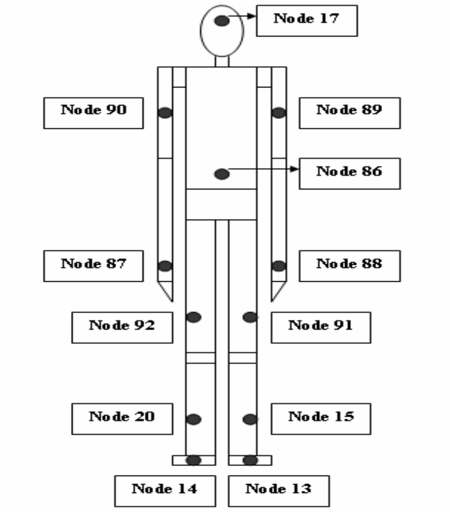

Fig. 2 Node (Accelerometer) Placement on Human Body

Fig. 3 Wireless Radio Frequency Basestation

V. Data Acquisition Methods

Data acquisition is easily carried out with the aid of LabVIEW VISA (VISA) programming function that facilitates the communication of the accelerometer and PC, via the USB base station. The VISA function along with other functions such as the 'type cast', that converts ASCII codes to HEX values has allowed for significant progress to be made in this work. The data acquisition method used for obtaining data in this paper is called Triggering. The following section will discuss the data acquisition method and its raw output data format in detail.

A. Triggering

When the trigger command is initiated by the user, the corresponding HEX values for this command will be generated, and transmitted via RF to the accelerometers at a remote location (test subject's body). This command then activates (Triggers) the sensor to begin performing a data logging session for a period of time specified by the user, within the software interface. During the entire process of data logging, data will be recorded onboard the sensor, as depicted in Fig. 4, and will be transmitted back to the computer via radio frequency for further processing.

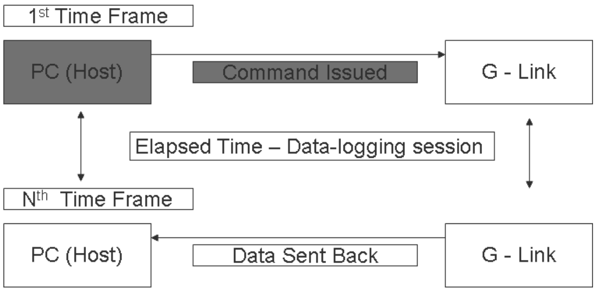

Fig. 4 Flow of data during a trigger session

The triggering function is designed to run indefinitely, whereby at the end of a data logging session the sensor would begin triggering once again until the user instructs it to turn off. The flow diagram in Fig. 5 depicts the designed triggering process. This feature allows for continuous monitoring of gaits to be carried out, and to monitor their dynamical properties.

Raw data obtained from the sensor, are in terms of byte streams, these byte streams are in ASCII format and have to be converted to the HEX values before converting into their decimal representation as they are arranged in terms of Most Significant Bits (MSBs) and Least Significant Bits (LSBs) in alternating order. Converting these HEX values to Decimal values requires nothing more than a simple step as formulated in (1).

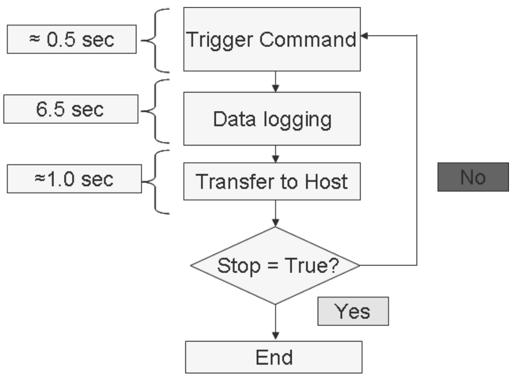

Fig. 5 Process flow for capturing data

$$Decimal = (MSB\_byte * 256) + LSB\_byte \qquad (1)$$

Once data has been converted from HEX to Decimal, the data is now represented as 'accelerobits' and is not a representation of acceleration as yet. In order to convert 'accelerobits' into a kinematical parameter such as acceleration, then the procedure as shown in (2) has to be carried out. The offset and gain values found in (2) refers to the calibration values of the accelerometers. These values are readily available when the accelerometer are calibrated, and remain constant till the next re-calibration routine. It is after these conversions that the data is ready to be represented as graphical outputs (Fig. 6 and Fig. 7). The acceleration obtained is channel specific depending on its orientation with respect to the gravitational field.

Once the acquired data is converted into measured instantaneous acceleration, other kinematical parameters such as distance traveled and the angle of rotation along the mid-sagittal plane can be easily calculated and presented to the motion regeneration part [3], to perform motion regeneration of the captured data.

$$C1 = \frac{(AcceleroBits\_C1 - Offset\_C1)}{Gain\_C1} \times 9.81$$
$$C2 = \frac{(AcceleroBits\_C2 - Offset\_C2)}{Gain\_C2} \times 9.81 \qquad (2)$$
$$C3 = \frac{(AcceleroBits\_C3 - Offset\_C3)}{Gain\_C\_3} \times 9.81$$

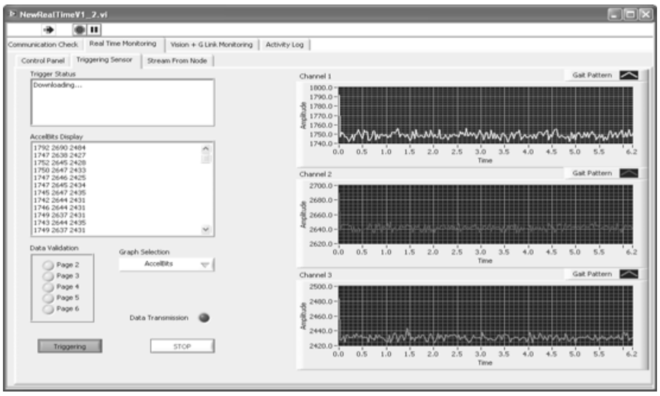

Fig. 6 Data Acquisition Panel

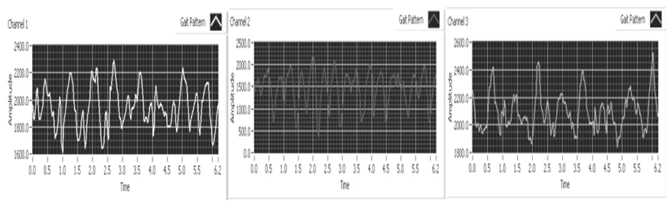

Fig. 7 Graphical representation of accleration after conversion in (2)

VI. Data Reliability

When dealing with wireless (RF) data transmission, among the questions to be addressed is the reliability of the transmission medium. A method, by which a system ensures that all data has been received, and that there has been no loss of data during transmission, is extremely important to ensure the validity of a certain data set. This section deals with the method by which data reliability is ensured for the wireless data transmission of this system.

Data is stored on board the sensor in term of pages of 267 bytes in length. When raw data first arrives from the accelerometer, it is in the ASCII format where it will be converted into its equivalent HEX. Once the data is in its HEX representation, the data logging header byte string has to be located; the header byte string is a 12 byte long string that contains user defined setting for the data logging session, such as sweep rate and duration of the data logging session. The first two bytes of this header byte string is always a constant with values of 0xFF. This is the basis used to identify the beginning of the data logging header byte string. Table 1 shows the representation of the data in the data logging header byte string.

TABLE I
TRIGGERING HEADER BYTES STRING [11]

Value Pair (Bytes)	MSB	LSB	(MSB*255) + LSB	Remarks
1 & 2	255	255	65535	Fixed Header
3 & 4	255	1	65281	Trigger ID
5 & 6	5	20	1300	Samples per Data Set during session
7 & 8	0	1	1	Internal consecutive session ID
9 & 10	0	7	7	Channel mask during session
11 & 12	0	4	4	Data logging Sampling Rate during session

As indicated in Table 1, data is arranged in terms of MSB and LSB, where byte 13 would be the MSB of the information in Channel 1 and byte 14 would contain the LSB of information in Channel 1. Bytes 15 and 16 would be the representation of Channel 2 while bytes 17 and 18, Channel 3, as shown in (2) [3]. It is then obvious that information of Channel n will be obtained at intervals of 6 packets from its first MSB.

Besides formatting data in this manner, the introduction of a checksum (3) also increases the reliability of the data obtained in terms of error checking. Each page has 2 bytes of checksum (MSB and LSB); these check sums are a representation of the entire data within the page.

$$Check\_sum = \frac{\sum\left(\sum C1, \sum C2, \sum C3\right)}{65535} \qquad (3)$$

The check sum calculation value in (3) will be compared to that which is obtained from the data set using the sum of values calculated in (2). If these two values tally then the data in the downloaded data set deemed valid, otherwise the data in the page will not be accepted. Possible errors that could happen in which the system would detect a transmission error [6]:

- Battery draw-down in the accelerometer
- Radio interference between base station and accelerometers
- Accelerometer's power is switched off
- Out of radio range condition between the base station and the accelerometer.

It is due to these reasons that the data acquisition method was chosen to be triggering of the sensors [3], followed by the download of data, as opposed to the streaming of data directly from the sensor. In triggering, when the sensor is triggered it is activated for a specified period of time, and can be located at any position outside the radius of transmission of the base station (5m) [5]. This method reduces probability of an error occurring due to the radio interferences and a situation where the accelerometers may be out of range.

The only time an error may occur is, when the test subject is out of range when the base station is trying to communicate with the node, upon completion of a data logging session. Alternatively, an error could occur if the battery's current draw drops below the required amount during data collection. However this error is easily avoided and is correctable, by simply ensuring each dry cell contains adequate voltage and current to power up the accelerometers long enough.

VII. LAWN BOWLING

A. An Overview

Lawn bowling is a game played on a large, rectangular, precisely leveled and manicured grass or synthetic surface known as a bowling green which is divided into parallel playing strips called rinks. In the simplest competition, singles, one of the two opponents flips a coin to see who wins the "mat" and begins a segment of the competition by placing the mat and rolling the jack to the other end of the green to serve as a target. Once it has come to rest, the jack is aligned to the center of the rink and the players take turns to roll their bowls from the mat towards the jack and thereby build up the "head".

A bowl may curve outside the rink boundary on its path, but must come to rest within the rink boundary to remain in play. Bowls falling into the ditch are dead and will be removed from play, except in the event when one has "touched" the jack on its way. "Touchers" are marked with chalk and remain alive in play even though they are in the ditch. Similarly if the jack is knocked into the ditch it is still alive unless it is out of bounds to the side resulting in a "dead" end which is replayed though according to international rules the jack is "repotted" to the center of the rink and the end is continued. After each competitor has delivered all of their bowls, the distance of the closest bowls to the jack is determined and points, called "shots", are awarded for each bowl which a competitor has closer than the opponent's nearest to the jack. For instance, if a competitor has bowled two bowls closer to the jack than their competitor's nearest, they are awarded two shots. The exercise is then repeated for the next end, a game of bowls typically being of twenty one ends.

In lawn bowling the stance and posture that the bowler adapts is very important before beginning the delivery action. The bowler needs to prepare for a delivery by anatomically aligning in the direction of the delivery by relying on their sensory and visual feedback [5]. Special care is also taken to align their feet in the delivery direction as shown in Fig. 8.

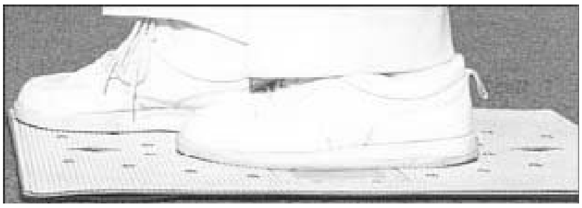

Fig. 8 Feet alignment before a delivery [9]

The erect posture of an upright stance provides a good perspective view of the head. It avoids leg join stress during preparations. An upright stance enables bowlers to apply a body momentum to augment the forces that produce a good bowl release speed. From the ‘set’ position in the fixed stance, only the arms move and provide dynamic force.

B. Motions Monitored

As seen in the previous section, lawn bowlers remain still after aligning themselves for a delivery. It is from this point on that the work in this paper concentrated on. The work concentrates on motion of the lawn bowler on the sagittal plane, identifying potential erroneous postures that could lead to injury, or an ineffective delivery.

A somewhat defective form that a bowler could use is a ‘crouch’, Fig. 9. Bowlers should avoid crouching, as crouching causes great amount of stress to be placed on both the knee joints [9]. A free step from a crouch is impossible. The knee joint of the opposite leg would bear the maximum stress exerted by the bowler.

A crouching stance necessitates some straightening of the legs and lifting of the body during the delivery movement so that the leading foot can advance without over-stressing of the opposite knee joint occurring. This lifting tends to have the incidental effect of moving body weight back from the balls of the feet to the heels. None of this extraneous movement contributes to simple and accurate delivery of bowls.

An erroneous posture such as the crouching stance can be easily detected along the sagittal plane, as it involves the flexion of the knee and lower back which can be easily captured by the sensors. A progression of the crouching stance as captured by the sensors after being remodeled is shown in Fig. 10 [5].

Fig. 9 'Crouching' Stance for a Delivery [9]

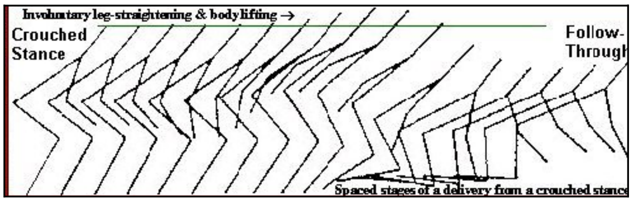

Fig. 10 Progression of the crouching stance

The principal action in any method of delivery is the pendulum like swing and forward swing of the bowing arm along the required delivery line. Bowlers should use the same action to deliver jacks and bowls.

A proper release posture would be, the knee of the trailing leg near the heal of the leading foot (Fig. 11), the weight of the body over the sole of the leading foot (Fig. 12) and the front knee ahead of the toes (Fig. 13)

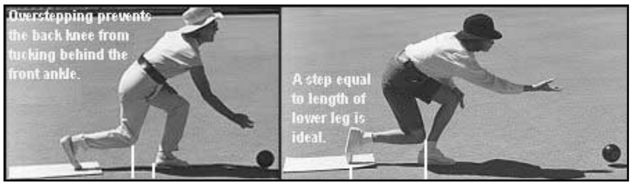

Fig. 11 Trailing foot knee near heal of the leading foot [9]

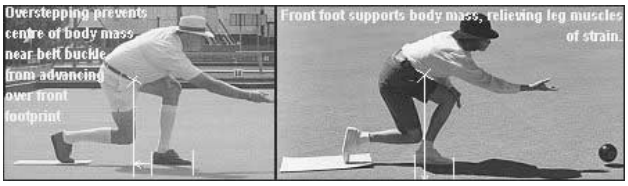

Fig. 12 Weight of body over sole of leading foot [9]

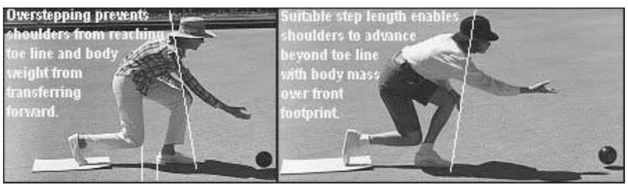

Fig. 13 Front knee ahead of toe [9]

C. Motion s in the Sagittal plane

Base on the movements studied, the critical motions to performing a good delivery in a lawn bowl lies on the sagittal plane. From anatomical position, the three primary movements occurring in the sagittal plane are flexion (Fig. 14), extension (Fig. 16) and hyperextension (Fig. 15).

Flexion includes anteriorly directed sagittal plane rotations of the head, trunk, upper arm, forearm, hand and hip, and posterior directed sagittal plane rotation of the lower leg. Extension is defined as the movement that returns a body segment to anatomical position from a position of flexion.

Sagittal plane rotation at the ankle occurs both when the foot is moved relative to the lower leg and when the lower leg is moved relative to the foot. Motion bringing the top of the foot towards the lower leg is known as dorsifelxion (Fig. 17) and the opposite motion, plantar flexion (Fig. 18).

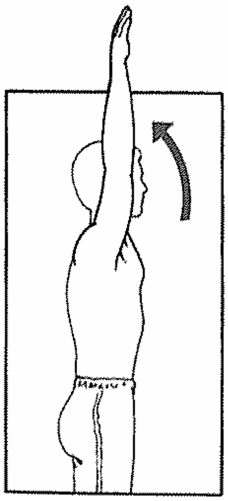

Fig. 14 Flexion [12]

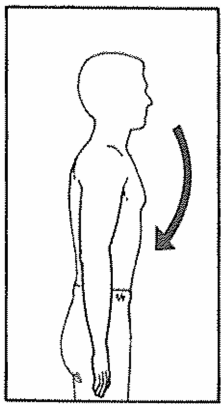

Fig. 15 Extension [12]

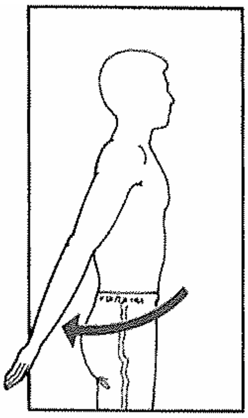

Fig. 16 Hyperextension [12]

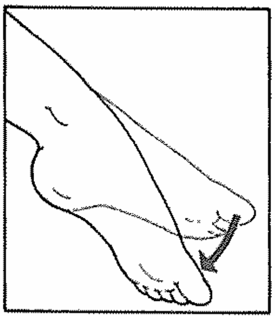

Fig. 17 Plantar Flexion [12]

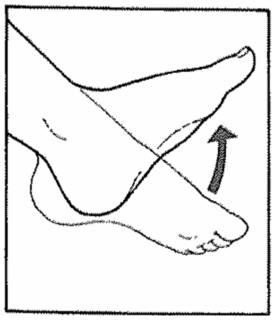

Fig. 18 Dorsiflexion [12]

D. The Lawn Bowler as a 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. In this work, a human stick figure is designed for displaying results of motion regeneration.

Some assumptions were made in this work; the assumptions will be discussed in detail, in the following sections.

1) Right Hand Biased

All the test subject available were right handed players, therefore data for naturally left handed players was not made available to us. It would be difficult to predict the way a left hander bowler would bowl so therefore the system is right handed biased.

2) Body Length Ratio

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 body segments, Fig. 19. 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 2 [5].

3) Trapezoidal Rule s

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 work, a very simple numerical analysis method is employed to convert acceleration to displacement, using the trapezoidal rule by means of double integration, further discussed in the following section.

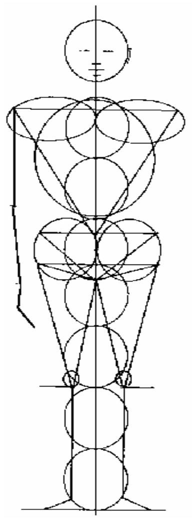

Fig. 19 Body Segment Lengths with Reference to the Head

TABLE 2
LENGTH OF BODY SEGMENT [5]

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

VIII. RESULTS & DISCUSSION

A. Accelerometers and distance traveled

In this work, we have used accelerometer to determine the distance travelled. Theoretically speaking, an acceleration time profile would give us a distance time profile if we perform a double integration on the set of data available. This method of arriving at the distance time profile would yield a certain error, drift error, which is caused due to the estimation procedure in the integration step. The value of this error is highly dependent on the integration routine which was chosen, and the sample size that is to be integrated.

We conducted a series of preliminary test to ensure that performing a double integration on an acceleration time profile would yield us a distance time profile with a small error margin. We tried this concept with different sampling sizes, to identify a possible sampling size.

If a sample size is too big, then the error in the integration would be integrated/ accumulated over a much larger sample size, hence possibly increasing the error margin of the readings. It is for this reason that the sample size that is to be integrated has to be selected with care.

Figure 19 shows the propagated error over time if the first point of the sample size was selected to be the first acquired data, and the 100th data acquired. An integration using the trapezoidal rule (4) was used.

$$I = (b-a)\frac{f(a)-f(b)}{2} \tag{4}$$

Where the first value of the acquired data is a and the 100th acquired data is b. The acceleration integrated in Fig. 20 and Fig. 21 are along the X coordinate (the horizontal plane). Fig. 20 depicts the propagation of error over the first integration and Fig. 21 depicts the accumulated error over the second integration to obtain the travelled distance.

As seen in Fig. 20 and Fig. 21, at the first instance of integration the error introduced is still linear, but changes into a logarithmic scale error when the second integration is carried out. The values for b and a in this calculations were 2000 readings apart. The data set captured in this graphs were still data, 0 ms^{-1} and 0 meters.

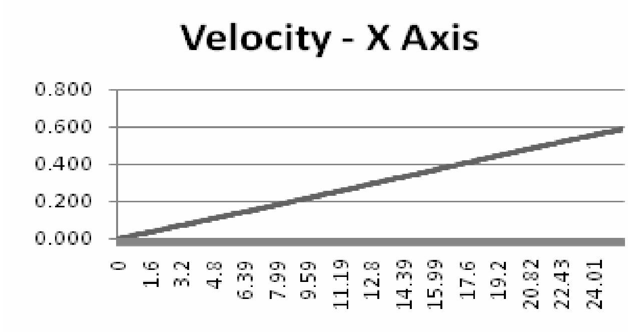

Fig. 20 First integration - Velocity Time Profile

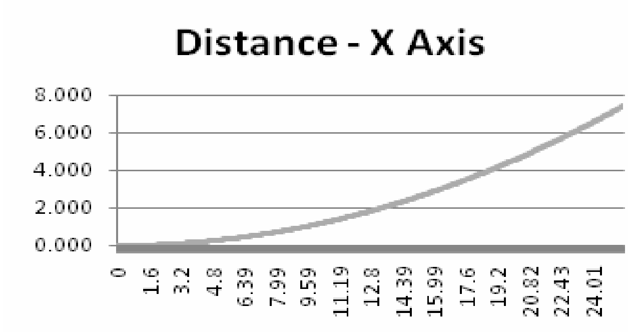

Fig. 21 Second integration - Distance Time Profile

After considering a few sample sizes, we found that the best sample size that yielded information with the lowest error, and in the fastest time is when we set the sample size to be at each step of data when it is acquired, where a = *data acquired in* T_1 and b = *data acquired in* T_2 (Fig. 22 and Fig. 23). This not only allows us to perform a real time monitoring, since we do not have to wait too long for the data to collect to the required sample size, but yields an error in the millimeters range.

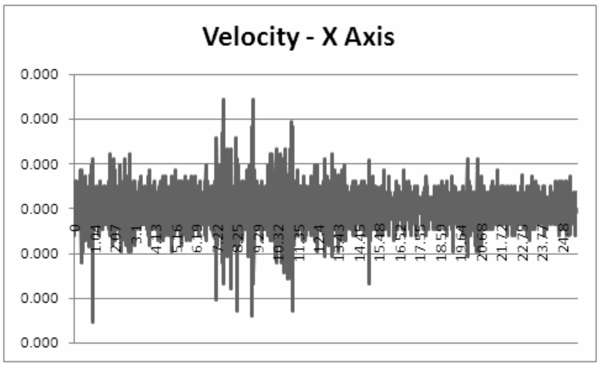

Fig. 22 First Integration - Velocity Time Profile

Fig. 23 : Second Integration - Distance Time Profile

B. *Accelerometers for motion regeneration – using distance*

From the various tests conducted, it is concluded that the right foot never moves from its position when a lawn bowler is in motion [7], therefore the tip of the right foot will act as the starting point for the calculations for the stick figure. The calculation for the stick figure involves simple trigonometric functions such as sine and cosine rules.

The initial point of reference was taken to be at node 14 (Fig. 2 – the right foot) and moved upwards from that point to node 20, node 92, node 86, node 91, node 15 and node 13. This covers the calculation for the lower extremity of the human body, the next stage would be to propagate the calculation upward, using the node situated at the centre of gravity of the human body, approximately at the hip (node 86). With reference to the readings obtained from the node at the hip the position of the two arms was calculated using nodes 90 and 87 for the right arm, while node 89 and 88 for the position of the left arm.

The motion is regenerated and plotted in the LabVIEW programming platform using the graphical output option which is available in LabVIEW. Figure 8 shows a screen shot of the system plotting the 2D position of a lawn bowler

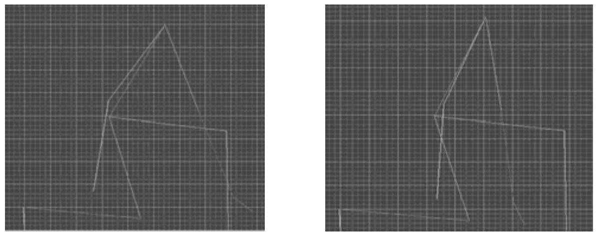

Fig. 24 Motion Regeneration in LabVIEW

C. *Accelerometers for motion regeneration – using angles*

Besides using the accelerometers to determine the physical distance traveled, the accelerometers can be used to determine joint angles of the segments. In Fig. 23 an accelerometer was attached to the test subject's wrist, where channel 1 was pointing towards the ground, channel 2 points towards the subject's body, and channel 3 points into the arm. A simple motion was tested. The action was to bring the wrist up by 90 degrees, from the graph we can clearly see the angular changes in the readings from 90 degrees to 0 degrees for channel 1 and 0 degrees to 90 degrees for channel 3 – 0 degrees is assumed to be on the transverse plane. Fig. 24 shows a similar motion, except the motion now requires the arm to be lifted up by 180 degrees. Similar results as in Fig. 23 are observed. From this observation, we can conclude that by using simple trigonometry, angle that each channel made to gravity can be observed. Inverse sine or cosine was used to find the orientation of the sensor relative to gravity.

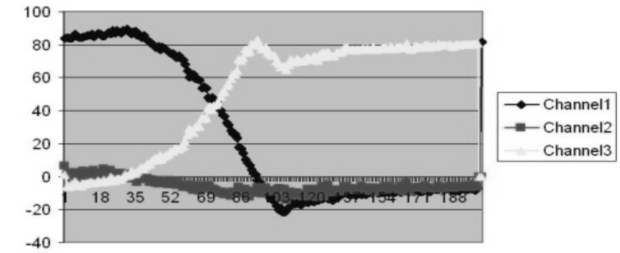

Fig. 25 Graph of Angle vs. Time for a 90 degree motion of the arm

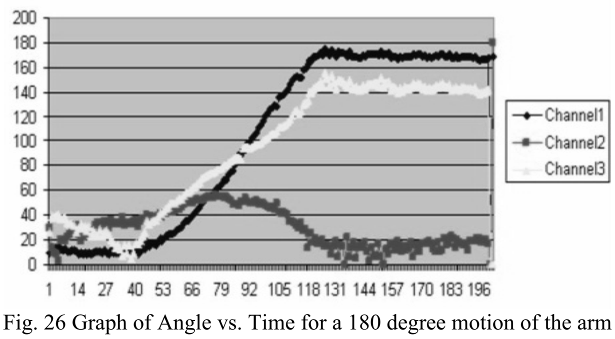

Fig. 26 Graph of Angle vs. Time for a 180 degree motion of the arm

IX. FINDINGS

A. Accelerometers for distance travelled calculations

In this work we found that determining the time interval of data points that we use to perform integration is very important. Using an interval which is too big will almost definitely result in a distance estimation that has a high percentage of error as shown in Fig. 21, in the previous section.

This finding coincides with the basic principal of how the trapezoidal rule for integration. The trapezoidal rule is the first of the Newton Cotes closed integration formulas. Geometrically, the trapezoidal rule is equivalent to approximating the area of the trapezoid under the straight line connecting *f(a)* and *f(b)* in (4). The concept applied for calculating the area of a trapezoid can be directly applied here for integration; where (4) the integral estimate can be represented as (5), where the graphical depiction of (5)is shown in figure 26.

$$I \cong width \times average\_height \tag{5}$$

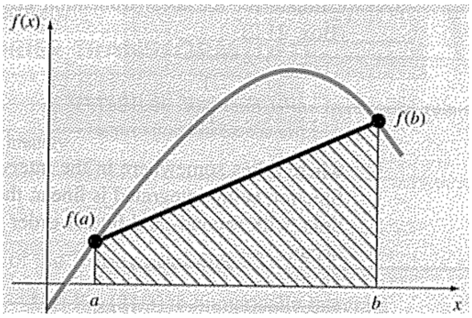

Fig. 27 Trapezoidal Rule – Concept [13]

From Fig. 27, it becomes obvious why estimating the appropriate time interval is essential. If the estimation period is too large then significant area under the graph may be missed, the non-shaded region. Fig. 28 shows how improving the interval period *a* and *b* reduces the estimated error, the approximation is closer to the curve, a smaller are of error (non shaded region).

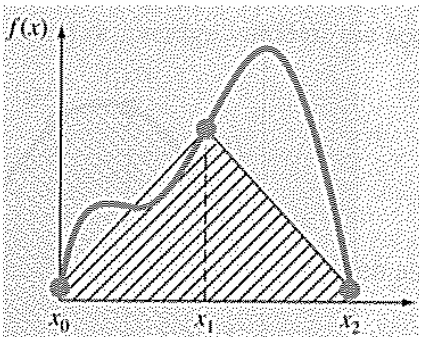

Fig. 23(a)

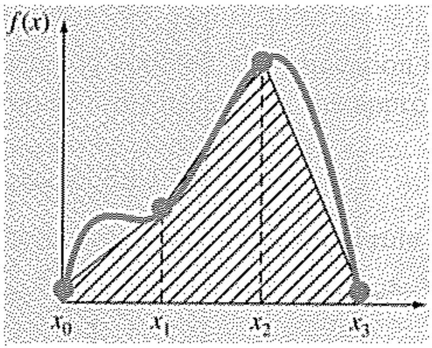

Fig. 23(b)

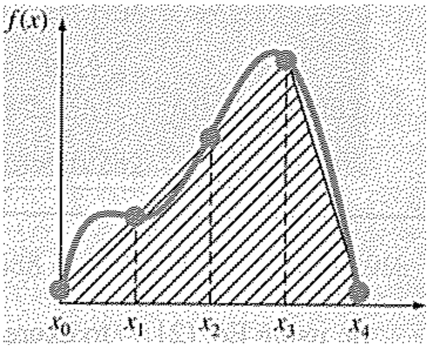

Fig. 23(c)

Fig. 28 Estimation of area under the graph with smaller intervals [13]

The trapezoidal rule is also a simple and straight forward method of integration that can be applied to the data set, if real time data is to be obtained. In the trapezoidal rule, we only require two data points before integration can be performed, as opposed to the Simpson's 1/3 and 3/8 rule, which require more points before they can perform integration.

The number of points required before integration can be performed, indirectly influences the time delay introduced in the system before the results can be produced to the end user.

B. Accelerometers for angles determination

From Fig. 25 and Fig. 26, it was found that accelerometers can be used to determine/ estimate angle position of the human body segment along the horizontal plane, as there would be a change in the earth's gravitational vector acting on the principal axis of the accelerometers [8].

This fact enables us to perform a 2D modeling that is based on the angles collected from the horizontal plane. However, if a 3D model is to be generated, rotation about the vertical axis will have to be considered at some point in time of the motion.

As previous discussed, rotations on the vertical axis will not result in a change of the Earth's Gravitational vector, that is acting on the principal axis of the accelerometers. This poses the major limitation in the accelerometers to be used as an instrument to measure and model a 3D motion.

X. FUTURE WORK

Possible future work that could be done along this direction would be definitely to consider a 3D model of the motion. In order to perform this, a combination or series of sensor combination will have to be considered. Among possible sensors that could be used to model and 'capture' a motion in a 3D space would be to include sensors which are capable of monitoring motions in a 3D space. Sensors such as *magnetometer, angular rate sensors* and *inertial sensor* are among potential suggestion that would be looked into, for performing a 3D motion capture, as these sensors are all capable of measuring rotations along the vertical axis.

XI. CONCLUSION

Two methods that were used to regenerate the human motion were presented. The first used the acceleration time profile to arrive at the distance time profile, before regenerating the human motion on the stick figure. The second method presented used the angles generated with respect to rotations on the horizontal plane to perform the motion regeneration.

The designed system consists of easy-to-wear sensors to minimize the setup time. It uses minimum number of sensors to fully describe the upper extremities of the lawn bowling motion. The complete motion data of this system is able to be downloaded to a desktop PC via wireless USB base station. The proposed system has demonstrated the use of accelerometers for motion analysis.

In order to have a 3 dimensional motion representation, it is found that dependence on accelerometer readings alone is in sufficient to provide a clear picture of the motion that has been monitored. The introduction of a second type of sensor, a gyroscope in particular, may improve the quality of the readings obtain due to its ability to measure the changes in angle with respect to the gravitational field.

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