Data Visualisation from Medical Sensors

Inertial Sensors for Stroke Rehabilitation

Ahmed Alharbi, Dr. X Wang, Dr. K Kim

Multidisciplinary Nanotechnology Centre, College of Engineering, Swansea University, Swansea UK

Email address: Alharbi.ksa.rus@gmail.com

Abstract— this research project is based on how inertial sensors data can be acquired and visualised in 360 degrees, in all 3D-dimensions, to monitor a patient's health condition in medical rehabilitation. Broadly speaking, the demand of medical rehabilitation and diagnosis centres for new advanced technologies with low cost and small size have been remarkably high as they have been facing difficulties with disabilities in human being functionalities. Such a device would support medical rehabilitation by providing a real-time monitoring system for human movements, improving the diagnosis and rehabilitation techniques. Thus increase the quality of patients' lives.

Keywords— *Stroke; diagnosis; inertial sensor; motor system; rehabilitation.*

I. INTRODUCTION

This research project is dedicated for improving stroke rehabilitation diagnostic techniques, by using inertial sensors alongside with the demonstrations on how these sensors data can be acquired and visualised in 360 degrees; in all 3D-dimensions, to monitor a patient's health condition in medical rehabilitation. Generally speaking, the number of stroke patient and disabled people needing medical support is increasing. Not only this, but also the demand of medical rehabilitation and diagnosis centres for novel sophisticated technologies with low cost, small size and more accuracy has been significantly high. This is apparently due to the lack of technologies provided and the complications associated with human motor impairments. If these areas could be improved for diagnosis and rehabilitation techniques, quality of patients' lives would be increased [1].

It is believed that inertial sensors are capable of tackling such a global devastating issue by supporting and providing medical rehabilitation centres with a reliable monitoring system for human movements, which could also be adopted to allow real-time analysis. Researchers have shown a dramatic decrease on the medical demand associated with stroke rehabilitation since the invention of the state of the art inertial sensors has been released to the market [2].

These electronic devices are consisted of 3 accelerometer and 3 gyroscopes to continuously measure and report the orientation, velocity, position and acceleration for a moving object in 3D space and real time, which represents human movements, without even the need of external references [3]. These sensors would provide reliable and feasible systems with high speed processing system and data acquisition with small size and low cost for the benefit of medical rehabilitation. As mentioned, stroke rehabilitation is an example of the major problems that has been outlined by rehabilitation centres in which the patient is experiencing some limbs moving disabilities. Despite the fact that some functional abilities can be

recovered spontaneously, but rehabilitation is still an on-going process in which the patient has to do exercises repetitively in order to get fine control of their limbs functions. Theoretically, by using this electronic device, motion patterns can be identified and corrected in the event of having undesirable motion behaviour; therefore, inertial sensors are the vital component to consider for a rehabilitation system, which would take such a system to a higher level or stage of medical sophistication, as it could potentially enhance the efficiency of monitoring the patient's health condition as well as improving the quality of life for all. In this study, analysis of motion was performed, considering three rotational motions (pitch, roll and yaw), using inertial sensors alongside with programs and softwares, like the Graphical User Interface (the arduimu demo program), Matlab, Labview and Excel. Such analysis is aimed to visualise inertial data in three dimensions to aid and improve rehabilitation diagnosis and monitoring systems for the benefit of stroke rehabilitation centres.

II. STROKE REHABILITATION

A. Stroke

Stroke is a common health-care problem across the world that is serious and vital. According to the stroke centre statistics department, more than 140,000 people die from stroke and about 795,000 people suffer from stroke, in which 600,000 of them experience the first injury and the other 185,000 have a recruit attack each year in the U.S.A. In addition to this, the British National Health Services (NHS) claims that the number of people suffering from stroke is approximately 150,000 cases annually in the U.K. Both mentioned institutions stated that the third leading cause of deaths is stroke, after heart diseases and cancer, and it is also the main cause of human-body motor disability [4], [5].

Such a medical condition is monitored and treated by doctors and clinicians in medical rehabilitation centres. Most of these rehabilitation centres and hospitals have their own stroke unit, which is primary focused on maximising the cognitive and functional abilities of the patients and setting them back to the community.

However, stroke is medically defined as a medical disorder in which there is disturbance or obstruction of blood supply to the brain, leading to the reduction of brain cells nutritions and oxygen, resulting in rapid loss of brain functions. This is considered to be a medical emergency since it can cause permanent neurological damage, complications and even deaths. In addition to this point, stroke also show symptoms like loss of balance, difficulty with walking, impaired ability to grab objects, muscles fatigues and lack of coordination. High blood pressure,

34

old age, diabetes, high levels of cholesterol, excessive smoking and alcohol drinking are factors that participating in causing such a disorder [5].

Medically speaking, patients with stroke survive the initial injury. But they sadly suffer from the long-term impairments and activity limitations which have shown numerous psychological impacts on patients and their families. Improving neurological systems and regaining lost functions could be achieved by having patients to do repetitive and intensive training of daily basis activities (such as setting, standing and lifting etc.) over periods of months or years [6].

B. Current Approaches: problems & suggested soluotion

As part of stroke rehabilitation, quantitative and qualitative analyses are used as diagnostic techniques and then combined for final medical decision.

Diagnostic qualitative analysis for stroke rehabilitation is defined as a descriptive statement of the body movements, which is expressed in terms of the motion characteristics, by visually observing and analysing the movements performed. Qualitatively, medical diagnosis of stroke is dependent upon the patient's age, medical record, gender, and background. Not only that but it also relies on the clinician's knowledge of the task performed (techniques or kinematics of the performance), the therapist's perception views, technical errors and diagnosis outcome [7].

Quantitative analysis report is based on figures rather than words in which a test or experiment is conducted, with the aid of instrumentations, to numerically analyse the motor system and relate the outcome to the qualitative report. Stroke rehabilitation quantitative study is performed by using electromyography devise, EMG, which detects the electrical activities of the skeletal muscles, and then the acquired data is plotted for further analysis.

With regard to existing approaches used in rehabilitation centres and hospitals for body movements and positions monitoring, ''these require access to specialised equipment, such as EMG, and a dedicated laboratory set-up, or rely on clinicians observation and patient recall'' [8].

Even though EMG is closely related to the muscle forces, vertical inclined motions of involved body parts are affected by gravity in which EMG seems to be incapable of indicating the actual motions. This shows limitation of the mentioned measuring device, although it is expensive and huge in size.

⊠ EMG:

Dimensions: Length 152 mm, Width 89 mm, Depth 35 mm
Average price: £ 500 per device.

Furthermore, qualitative diagnosis is performed by therapists, manually measuring the angles of motion, counting for steps and visually analysing the movements of the patient's given task [8].

After all, there seems to be two areas of improvements and these are the cost, accuracy and size of the technological measuring devices and the therapist's knowledge of complex or professional human motions.

III. PRINCIPLES & EXPERIMENT

This section is only concerned with the scientific concepts behind Human motor and inertial sensors, in which the human motion is defined and analysed.

A. Human Motor

It is a system consisted of neurons, muscles and bones in which motions are defined and coordinated by the neurological system and then put into action by the skeletal system. Such a motor system could be analysed using human biomechanics, which are the sciences focused on the forces (internal and external) acting upon the body and their effects which result in coordination being altered [9].

- Kinematics of the human body:

It is the branch of biomechanics that is concerned with the study of movements, considering the motor forces as well as the analysis of the forces impacts on that particular motion, from geometrical views represented in six degrees of freedom by allowing 3 axes for angles of rotations and displacements [9].

- Motor forces:

These could be internal as well as derived from tissues and the body mass or of other body segments. Forces are classified as gravity, muscle contraction, friction and ground reaction forces. E.g. Body Mass is acting vertically, gravity (ground reaction) is acting vertically in the opposed direction, resulting in balanced net forces.
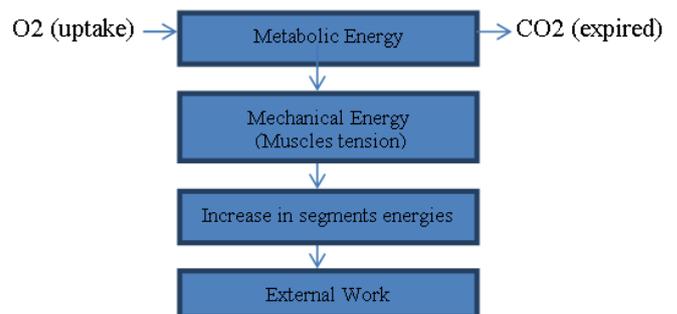
- Human processing of motion:

Figure 1. Shows how motion is produced.

- Motions:
1. Linear (translation):

It is a uniform motion in which all systems parts are moving at the same speed and direction. In another word, such a system moves as a unit and portions of the body do not move relative to each other. It is also thought of as motion along a line such as a straight line and it is referred to as a rectilinear, whereas; motion represented as a curve is called curvilinear.

2. Angular:

It is the rotation around an imaginary centre line known as the axis of rotation which is perpendicular to the plane in which rotations occur. For example, stripper bars or vortex. In another word, when a body is rotating; portions of the body are moving constantly relative to each other [9].

3. General Motion:

It is the most existing motion forms of the human body which is just basically the combination of the two mentioned motions.

- Mechanical systems for motion:

In order for proper identifications of the movements performed, a mechanical system has to be well defined to clearly analyse the motion of interest.

- Movement Terminology:

''When the human body is in anatomical reference position, all body segments are considered to be positioned at zero degrees. Rotation of a body segment away from anatomical position is named according to the direction of motion and is measured as the angle between the body segment's position and anatomical position'' [9].

- The Anatomical (cardinal) reference system:

It is a standing position of the human body, bisecting the mass of the body in three dimensions. ''but is the body orientation conventionally used as the reference position or starting place when movement terms are defined'' [9]. This reference system is consisted of three imaginary planes, which are the sagittal, frontal and transverse planes. In motor diagnosis, if a body is standing in the anatomical reference position, there is a single point called the body's centre of gravity where all cardinal planes intersect. ''These imaginary reference planes exist only with respect to the human body'' showing the motion in two or three dimensions. For example, when a movement of interest is two-dimensional, the analysis can be extended by adding a z-axis perpendicular to the x-axis and y-axis and measuring units away from the x, y plane in the z direction, resulting in three dimensions [9].
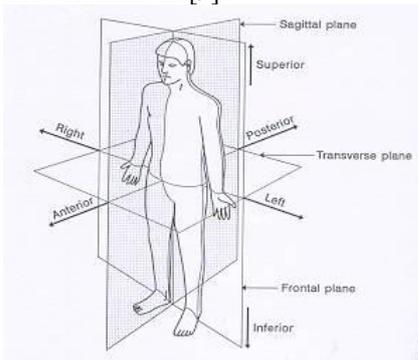

Figure 2. Shows anatomical reference plane [20].

i. The Sagittal (anteroposterior) plane:

This plane separates the body vertically into two equal halves, left and right. Movements associated with such a plane could include flexion, extension and hyperextension.
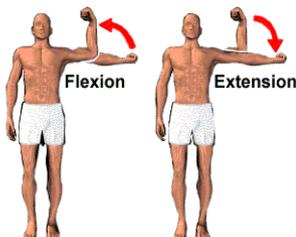

Figure 3. Shows sagittal movement type [20].

ii. The Frontal (coronal) plane:

The frontal plane divides the body vertically into two equal halves, front and back. Abduction and adduction are the most common types of movements involved in this plane [9].
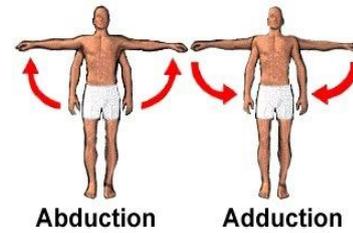

Figure 4. Illustrates the frontal movement type [20].

iii. The Transverse (horizontal) plane:

Such a plane splits the body horizontally into two halves with equal mass, top and bottom. Rotational movements are considered to be the body movements of such a plane [9].
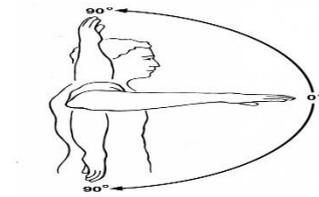

Figure 5. Displays transverse movement type [20].

B. Inertial Sensors

The word sensor is thought of as a device that detect or sense physical quantities into an electrical signal, then the signals are used for analysis, whereas; the word inertia is defined as the tendency of an object to resist any change in its motion. Historically, these sensors are used for aircraft inertial guidance systems and spaceships until it has been introduced to the medical field [10].

- The Inertial Navigation system (INS):

It is the field that focuses on the process of monitoring and controlling the movements of an object. This system is basically a navigational aid that uses computers combined alongside with accelerometers, gyroscopes, manometers or a combination of those, to continuously determine; by dead reckoning process, the orientation, velocity and position of a moving body without the need of external references. Those mentioned tools used in INS are called IMU (Inertial Measurements Unit) which are electronic devices that measure and report the velocity, orientation, position and gravitational forces. Such a system is based on the body initial velocity, attitude and position and subsequently measuring attitude rates and accelerations. Newton's laws of classical mechanics are what the operation of inertial navigation systems (INS) relies on. Such a navigation system is thought to be the only of its type that is not relying on external references [11].

- The Inertial Reference of Frame (IRF):

It is a coordination system which describes time and space homogenously. It is basically the point of view from which the system is observed at constant velocity or acceleration in which Newton's first law holds true (if there is no net forces acting on a body, then its velocity is constant in which the body is either

at rest with zero velocity or moving with constant speed) [11], [12].

- The Dead-reckoning process:

It is the process of computing a body actual position by using a pre-calculated position or fixed one based on approximated or known speed over elapsed time, which has some cumulative error, but INS provides very accurate directional information (calculate the position based on time and velocity) [13].

- Accelerometer:

It is a motion sensor which measures the linear and angular acceleration of a moving object and it acts like a damped mass upon a spring. So, when acceleration is experienced by an accelerometer, the mass is displaced to the point at which the spring is able to accelerate the mass and then acceleration is given by the measured displacement. In INS, three axes accelerometers are combined and aligned orthogonally (perpendicular to each other) to provide acceleration in all 3D [11].
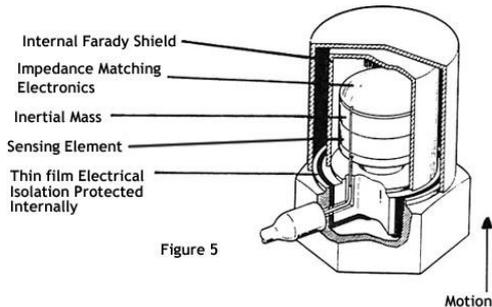

Figure 6. Displays a schematic diagram of an accelerometer [20].

Accelerometer data: It is obtained by double integration of the accelerometer's data, which is used to determine the absolute position and orientation of the device excluding the gravitational one. Direction of acceleration is observed when the device is at rest and orientation is computed by using the trigonometry.

- Gyroscope:

It is a rotation sensor which measures or maintains orientation based on angular momentum of the moving object and it behaves like a spinning wheel or a disk in which axes are free to assume any orientation. These orientations are not fixed due to the external torque, which is the tendency of a force to rotate an object, therefore; a pivot (gimbals) is used to minimise the torque, making rotations on a single axis. In INS, three gyroscopes are combined to allow measurements of velocities in all 3D.
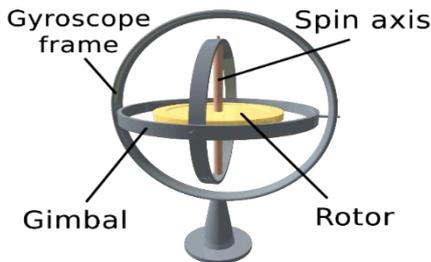

Figure 7. Illustrates a schematic diagram of a gyroscope [20].

Gyroscope data: This type of data is obtained by integrating the rotational velocities produced by the gyroscope [11].

- Combined accelerometers and gyroscopes:

Such a combination will lead to accurate results in which the sensor is in a fixed position that allow resetting the position and orientation data. Not only that but also allowing the measurements to be expressed in six degrees of freedom. These six degrees of freedom refer to the freedom of a rigid object to move freely in the three dimensional space, translations (forward/backward, up/down and left/right) and combined with rotations (yaw, pitch and roll) [14].
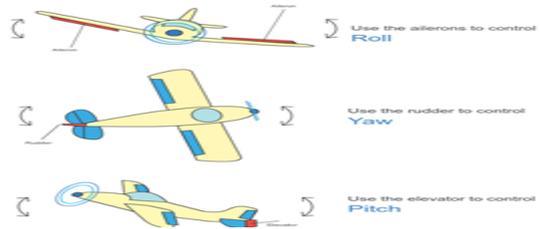

Figure 8. Shows an airplane performing pitch, roll and yaw [20].

☒ Note: Both mentioned devices are made in small size using MEMS technology. (Microelectromechanical system).

- Mathematics behind inertial sensors (the theory of operation):

Arduino v2 flat inertial sensor uses three gyroscopes and three accelerometers to maintain a model of the board's orientation in space using DCM (directional cosine matrix), which is a vector system in which the vectors are the cosines of the angles between the three coordinate axes and the vector. Direction cosines method is one way to construct a rotation matrix and Euler angles method is another way [15], [16].

R is the rotation matrix from frame A to frame B,

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = R \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} \tag{1}$$

R in terms of its components

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} \tag{2}$$

The unit vector b_1 can be expressed in the coordinates of frame by selecting the first row of R

$$R_{11} \times a_1 + R_{12} \times a_2 + R_{13} \times a_3 \tag{3}$$

R_{11} is the amount that b_1 extends along the a_1 direction

$$R_{11} = b_1 \, a_1 \tag{4}$$

Using the dot product rule:

$$R_{11} = |b_1| . |a_1| \cos\theta_{11} = 1 \times 1 \times \cos\theta_{11} = \cos\theta_{11} \tag{5}$$

Where $\cos\theta_{11}$ is the angle between b_1 and a_1, doing this for all then we have:

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} b_1.a_1 & b_1.a_2 & b_1.a_3 \\ b_2.a_1 & b_2.a_2 & b_2.a_3 \\ b_3.a_1 & b_3.a_2 & b_3.a_3 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

$$= \begin{bmatrix} \cos\theta_{11} & \cos\theta_{12} & \cos\theta_{13} \\ \cos\theta_{21} & \cos\theta_{22} & \cos\theta_{23} \\ \cos\theta_{31} & \cos\theta_{32} & \cos\theta_{33} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} \tag{6}$$

This is a direction cosine matrix. Each entry is the cosine of the angle between some unit vector of B and some unit vector of A. Notice that every direction cosine matrix is a rotation matrix, and every rotation matrix can be written in terms of direction cosines. The important thing to realise is that these nine numbers, whether you think of them as direction cosines or just as elements of a rotation matrix, are another way to parameterise orientation. This representation has no singularities as did the Euler angle representation. This representation is subjected to constraints because not every matrix is a rotation matrix [17].

It is useful to know one more thing. Notice that row 1 of the direction cosine matrix gives the coordinates of b1 in frame A. For example, the coordinates of b1 are

$$[R_{11} \quad R_{12} \quad R_{13}]^T \tag{7}$$

in frame A, as we said before. This means that direction cosine matrices (equivalently, rotation matrices) are often easy to write by inspection. For example, let us say frame B was oriented such that axis b1 is aligned with -a2, axis b2 is aligned with a1, and b3 is aligned with a3. Then the coordinates of b1 are

$$[0 \quad -1 \quad 0]^T \tag{8}$$

$$R = \begin{pmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{9}$$

C. Experiment

This section covers the equipment, methodology and results of the experiment.

- Equipment:
1) Two ArduIMU v2 flat inertial sensors. (provided by project supervisor):
- ☒ Arduimu inertial sensor:
  Dimensions: 4 mm × 4 mm × 1.45 mm
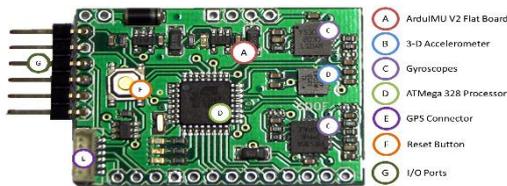 Average Price: £100 per device.

Figure 9. Shows a v2 flat arduimu sensor [20].

- ❖ Arduimu kit contains one board and one six-pin right angle header.
- ❖ It needs soldering the header to the board.
- ❖ It is consisted of tri-axis angular rate sensor (gyroscope).
- ❖ It comes with tri-axis accelerometer.
- ❖ It has a Digital Motion Processing unit (allow for complex motion fusion by dealing with fusion sensor).
- ❖ It gives an output of digital data formatted in Ascii, American Standard Code for Information Interchange, form, which is a character encoding scheme based on the English alphabet. Such a coding system represents text in computers.

- ❖ It has ±3% and ±0.83% tolerances for accelerometer and gyroscope respectively.
- ❖ Output data is given in terms of pitch (x), roll (y) and yaw (z) movements.
  An example:
  Ascii: Roll=-00036, Pitch=-00001, Yaw=01928, Data=AN0:-1,AN1:1,AN2:0,AN3:0,AN4:-1,AN5:102,RLL:-0.36,PCH:-0.01,YAW:19.28, this data was imported into matlab as a matrix form, only the overall movements were considered and imported which are Pitch(x axis), Roll(y axis) and Yaw(z axis).
2) Two FTDI cable (were personally shipped online).
3) Arduimo-demo software (graphical user interface).
4) A PC, personal computer.
- Methods & Procedures:
- ❖ The arduimu demo software, graphical user interface, was downloaded from the arduimo website.
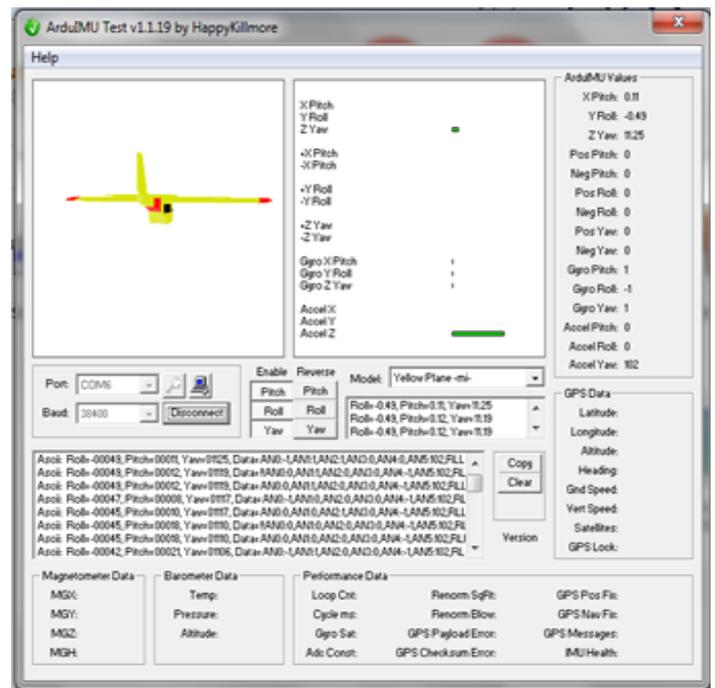

Figure10. Shows the demo program supporting the ArduIMU sensor graphically.

- ❖ Labview software was also used for graphs comparison and simulations. (used in lab 43b)
- ❖ Soldering was performed in Lab 43b, which is the electrical and electronic lab, for all the three headers and sensor boards.
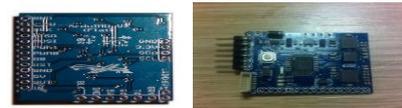

Figure 11 & 12. Shows arduimu sensor before and after soldering the six-pin header.

- ❖ The 6-pin header was connected to the FTDI cable and then the FTDI cable was plugged into the PC for power supply.

Figure 13. Displays the sensor being connected to the FTDI cable and also to the PC.

- ❖ Configurations of the sensor and the software were sat up, making sure the software could read data of the sensor.
- ❖ Three motion cases were performed based on actual measurements using the sensor and the demo programme, pitch, rolls and yaw rotations respectively.
- ❖ Output results were visualised for motion patterns and then recorded using the GUI.

Pitch(x)	ROLL(y)	Yaw(z)
-0.01	-0.36	19.28
0	-0.37	19.28
-0.01	-0.39	19.28
0	-0.32	19.28

- ❖ Data was then saved into text files.
- ❖ Text files were imported to, the state of the art calculator & GUI, Matlab using the import file function.
- ❖ Only pitch, roll and yaw data was imported and then plotted using Excel and Matlab plotting functions for angular velocities display.
- ❖ Analysis of motion patterns was performed using the following: the sensor output data, motion representation in the GUI and the plotted graphs of the performed movements.
- • Results:
- ❖ Case 1: Pitch Rotation.

In this case study, only rotational pitch movement was performed showing the rotational motion (angular velocity) of the moving body about the y and z axes.

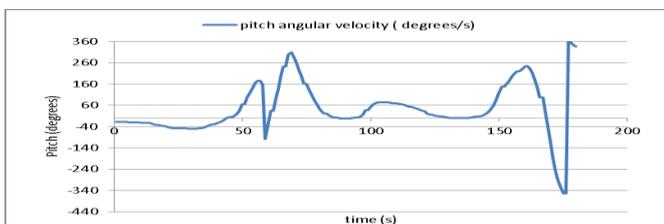Figure 14. Displays pitch movement in labview.
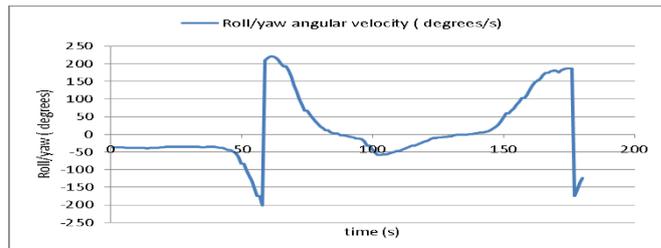

Figure 15. Shows pitch motion patterns.

Figure 16. Displays roll/yaw with respect to time.

- ❖ Case 2: Roll Rotation.

The sensor was rotated in a roll pattern movement to display the change of angular velocities in y with respect to x and z axes.
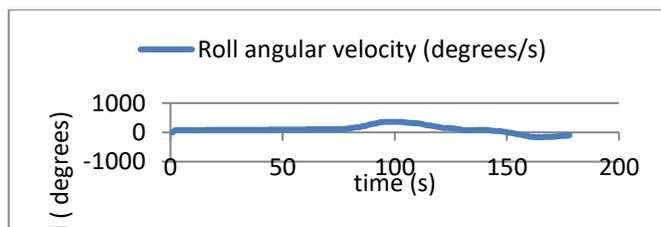

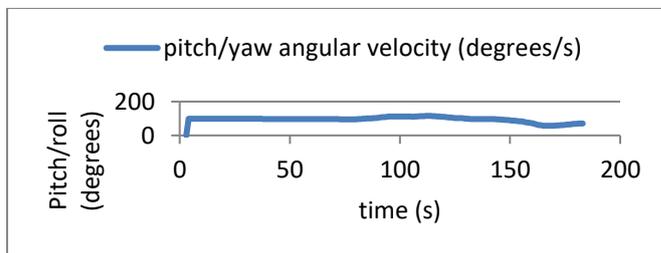Figure 17. Shows roll movement pattern.

Figure 18. Displays pitch/yaw with respect to time.

- ❖ Case 3: Yaw Rotation.

Rotation was applied showing angular velocities in the z axis, measuring units away from the x, y plane in the z direction.
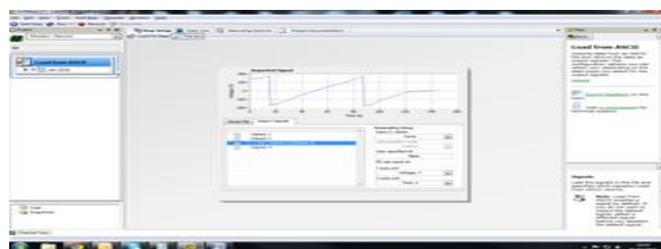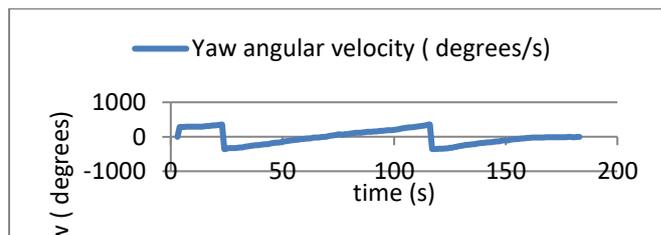

Figure 19. Shows yaw motion patterns.

Figure 20. Displays yaw with respect to time.

39

IV. DISSCUSSION & CONCLUSIONS

A. Discussion

In this research project, an experiment was conducted to perform three different actual rotational orientations, which were studied and analysed for the benefit of stroke rehabilitation centres.

Case 1: in this particular case study, only pitch rotational movement was concerned to indicate the motion behavior about the x axis in relation to the other two, y and z.

As seen from figure 15, the body was moving with a maximum inclination of +360 degrees and a minimum of -342 degrees in which the sensor was rotating around itself. Backward pitching was performed in which the head of the sensor was rotating towards the sensor holder. In another word, the senor started rotating by going upward towards the sky and then around itself. The time taking from one point to another determines the speed at which the sensor was moving. Such an example is seen in figure 15, first phase change is much faster than the second phase change in which roughly 1 s and 12 s were taken respectively. Figure 16, shows a graph of pitch motion plotted using the labview software for analysis boost. Case 2: roll rotational motions were applied to the sensor to investigate the motion patterns about the y axis relative to the x and z axes.

Figure 17, shows that the body started proper rolling to the left and right sides from roughly the point where the time is 80 sec. A complete roll was performed in which the sensor started rolling to the left and then towards the right in the opposite direction in which ±360 degrees angles range was covered between the approximated times 80 s to 130 s.

Case 3: in this motion study, the concern was on the yaw angular velocities to show the change in z with respect to x and y. Figure 20, displays the motion pattern of a pure yaw movement in which the body was rotating with the range of ±360 degrees in which the body was yawing to the left then to the right in cyclic movement patterns. Figure 19, shows the yaw motion pattern plotted using the labview software for supportive analysis.

B. Conclusions

Taking everything into account, the main observations found in this study are the capabilities of the arduimu inertial sensors to visualise motion patterns and their adequate accuracy. The performed motion patterns correspond to the obtained results excluding the sensor tolerances due to the tolerance levels being fairly acceptable. These tolerances would affect the results obtained by only 0.83%. Such as that ±360 degrees would become ±360 degrees with ±2.988, resulting in ±357.012 degrees instead. Not only this but also another observation is found in which inertial sensors seem to cost lower and have smaller sizes than EMG.

In this research project, an experiment was conducted to show how inertial sensor data could be visualised in ±360 degrees and represented in 3D for stroke rehabilitation motion tracking systems. As seen from the results and discussion that inertial sensors displayed strong & sufficient capabilities of indicating the motion of a moving object. In addition to this, it has also been seen in this article that these mentioned sensors can measure angular velocities within ±360 degrees range with adequate accuracy. Moreover, it is also shown that inertial sensors are manufactured in smaller sizes than EMG and also the cost of a single EMG device is approximately five times more expensive than a single inertial sensor. Since such a technology has met the criteria needed by stroke rehabilitation centres, therefore, these state of the art inertial sensors are the key and vital components which could improve tracking motion systems and thus enhance the efficiency of monitoring the patient's health condition as well as improving the quality of life for all.

❖ *Limitations & Recommendations*
- Multiple wireless sensors.
- GPS for data transmission.
- Video Cameras.

If we had the above listed components, we could have done a real-time analysis rather than an experimental one which ofcurse gives more accurate results and less time consuming; therefore, better diagnosis and treatments for stroke patients. Not only that but also gait analysis and more complex motions could be then performed [18].

❖ *Future Medical Applications*

It is believed that sensors data can be adopted into robotic training programs, in which the motion patterns of a normal person's movement is captured by inertial sensors and then sent and programmed into a robot. This robot, is apparently connected to the patient neurologically, receives the data and the commands from the patient's nervous system and then behaves and moves accordingly [19].

REFERENCES

[1] Zheng H, Black ND, Harris ND. Position-sensing technologies for movement analysis in stroke rehabilitation. Medical & Biological Engineering & Computing. 2005; 43:8.

[2] Zhou H, Stone T, Hu H, Harris N. Use of multiple wearable inertial sensor in upper limb motion tracking. Elsevier Ltd-Medical Engineering & Physics, SienceDirect. 2008;30:11.

[3] Kang C, Zhong S. Design of Data Acquisition and Processing System for IMU; 2008 International Symposium on Intelligent Information Technology Application Workshops-IEEE COMPUTER SOCIETY; 2008. p. 4.

[4] The Internet Stroke Centre [Internet]. http://www.strokecentre.org/patients/about-stroke/stroke-statistics/: The Internet Stroke Centre, USA; 2013.

[5] NHS. NHS. Stroke [Internet]. http://www.nhs.uk/conditions/Stroke/Pages/Introduction.aspx?WT.mc_id=110901: NHS; 2013.

[6] Sommerfeld DK, Eek EU-B, Svensson A-K, Holmqvist LW, von Arbin MH. Spasticity After Stroke : Its Occurrence and Association With Motor Impairments and Activity Limitations2004.

[7] Langhammer B. PhysicalTherapy Tests in Stroke Rehabilitation [Internet]. Norway2008 [cited 2013].

[8] Kemp B, Janssen AJMW, Van der Kamp B. Body position can be monitored in 3D using miniature accelerometers and earth-magnetic field sensors. Elsevier Science Ireland. 1998;109:5.

[9] Kinematic Concepts for Analyzing Human Motion HumanMotion.http://highered.mcgrawhill.com/sites/dl/free/0073 376442/928289/Chapter2.pdf; 2013.

[10] Technology TUo. Basic Principles of Inertial Navigation Finland: Tampere University of Technology; 2010.

[11] Woodman OJ. An introduction to inertial navigation. Cambridge, uk: University of Cambridge2007 Contract No.: 696.

[12] Frame of reference [Internet]. http://m.everythingscience.co.za/grade-12/06-motion-in-two-dimensions/06-motion-in-two-dimensions-05.cnxmlplus; 2012.

[13] Shala U, Rodriguez A. Indoor Positioning using Sensor-fusion in Android Devices. Kristianstad University: School of Health and Society, Department Computer Science, Kristianstad University2011.

[14] Shala U, Rodriguez A. Indoor Positioning using Sensor-fusion in Android Devices. Kristianstad University: School of Health and Society, Department Computer Science, Kristianstad University2011.

[15] http://howthingsfly.si.edu/flight-dynamics/roll-pitch-and-yaw. Figure8, Pitch, Roll and Yaw movements. 2013.

[16] Arduimu v2 flat [Internet]. https://code.google.com/p/ardu-imu/wiki/HomePage?tm=62012 [20/10/2012].

[17] Premerlani W, Bizard P. Direction Cosine Matrix IMU: Theory; 2010.

[18] Zhou H, Hu H, editors. Inertial motion tracking of human arm movements in stroke rehabilitation. International conference on mechatronics & automation; 2005; Niagara Falls, Canada: IEEE.

[19] Tapus A, Tapus C, Mataric MJ. User—robot personality matching and assistive robot behavior adaptation for post-stroke rehabilitation therapy. Intelligent Service Robotics. 2012;1(2).

[20] Figures 2: Anatomical reference plane, 3: Sagittal movement, 4: frontal movement, 5: transvere movement, 6: Accelerometer, 7: Gyroscope, 8: Airplane movement, 9: Ardumimu v2 flat [Internet]. https://www.google.co.uk/imghp?hl=en&tab=wi [20/11/2012].