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Development of A Low Cost Upper Limb Motion Tracking System with Real-Time Visual Output

Adzly Anuar, Khairul Salleh Mohamed Sahari
Centre for Advanced Mechatronics and Robotics
Universiti Tenaga Nasional
Kajang, Selangor, Malaysia
{adzly, khairuls}@uniten.edu.my

Ewe Chern Yue
Department of Mechanical Engineering
Universiti Tenaga Nasional
Kajang, Selangor, Malaysia
chernyue93@gmail.com

***Abstract*—This paper describes the work done in developing a simple low-cost system for tracking upper human limb motion system with relatively satisfactory accuracy and repeatability. The system mainly uses two inertial measurements units (IMU)-based sensor, connected to an Arduino Uno microcontroller, which are plugged to a personal computer (PC). An open source 3D visualization code is used to display the result motion. A prototype was built, which cost less than USD 50, and tested. The results from yaw, pitch and roll values show that the range of error percentage is between 0.17 to 6.24% with a relatively repeatable pattern.**

Keywords—motion tracking; low cost; upper limb; inertial sensor

I. INTRODUCTION

The need to track the motion of the human limb has led to many design and development of an effective motion tracking system. Nowadays, unfortunate stroke patients are suffering from limited movement in their limb due to their sickness. Traditionally, most of the physical therapy and rehabilitation assessment of stroke patients are based on judgment and observations from a physiotherapist. Hossein and Maryam indicates that the assessment method on how well is a patient performing a standard task relies heavily on the physiotherapist's visual assessment alone [1]. The assessment which are done by physiotherapist requires training therefore should be certified by respective panel. The assessment should be performed one on one between the physiotherapist and the patient.

However, these physical assessments done by human may be inaccurate due to several reasons one of which is the subjectivity of these behavioral and clinical assessment. Therefore, computing technology and sensors comes in play to assist in the physical assessment on the patients. These technologies can be used for motion tracking system which can then be used to track the motion of patients. In general motion tracking, there are two main families of sensors which have been commonly used for rehabilitation engineering, which are optoelectronics and non-optoelectronics type [2, 3].

Leder, Azcarate and Savage states that sensor fusion algorithms and human skeletal models are used in inertial sensors such as accelerometer and gyroscope for motion capture purposes [4]. For magnetic systems, Yabukami, Kikuchi and Yamaguchi shows that transmitter(s) and receiver(s) were used in a magnetic system for motion capturing applications [5]. Furthermore, Agrawal, Banala and Fattah describes about the wearable system which consists of several optoelectronics or non-optoelectronics sensors [6].

In optoelectronics, visual based motion tracking system may use contrast-based or depth-based techniques to analyse the position of the human limb using several cameras at different angles. An example of an advanced optoelectronics sensor is the Kinect sensor. An article published by Zhao, Espy, Reinthal and Hai Feng shows that by a single Kinect sensor can be used for rehabilitation exercises monitoring [7].

Beside using the motion tracking system for stroke patients, it can also be used and applied in the field of robotics where the motion captured can be used to control a robotic arm. Motion such as moving the upper arm, lower arm, legs and head movement can be easily tracked with such technologies. Sensors and computing technology have been improved and drastically advanced in terms of capability, size and computing power.

II. LOW-COST MOTION TRACKING SYSTEM

Generally, motion tracking system can track a human body's movement with high accuracy, precision and reliability compared to a physical assessment done by another human being.

The main problem with the current rehabilitation and motion capture system is that there are very expensive, complicated, difficult to use and requires expert's attention. The cost would basically depend on the ability, range of functions and performance of the system. Typically, a complex system with a lot of functions and abilities would cost more.

The main of the system developed in this project is to provide basic function of motion tracking with reasonable accuracy, at lowest cost as possible.

A review has been conducted on several different types of low-cost motion tracking system, looking into the method used as well as the main intended function of the system. Table 1 shows the summary of the review. It is observed that the cost

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of these systems are estimated in the range of thousands of dollars (USD).

TABLE I. REVIEW OF LOW-COST MOTION TRACKING SYSTEM

Method	Description	Cost[a] (USD)
Visual tracking system [8]	Low-cost visual visual tracking system using retro-reflective markers and CCD network cameras. Used to detect and compensate for patient motion.	Under 3,000
Infra-red LED with webcam and image processors [9]	Low-cost infrared interactiondevice. The system is mainly intended for motion tracking	Not specified
3D vison-based markerless [10]	Low-cost 3D markerless system using vision-based system for optimization of athlete performance.	Not specified
Inertial measurement units (IMU) with controller unit board [11]	Low-cost and light-weight motion tracking suit for capturing human body motions.	Not specified
Webcam with LabVIEW vision assistant [12]	A low cost real-time motino tracking for limb movement	1110 (approx.)

[a] The cost is based on the value given in their publication

III. SYSTEM DESIGN

A. System Overview

The system uses two IMU sensors which will be strapped on the upper arm and lower arm to track the angle and orientation of the user's limb. With the sensors, the angle and orientation of the user's limb will be captured and sent to PC via Arduino. Raw values from the sensor will first be filtered before usage. After filtering the raw values, the filtered values will be sent to a 3D visualization program where the movement of the user's limb can be visualized instantaneously. At the same time, the filtered values from both sensors will also be recorded and stored for post-processing and analysis purposes. Figure 1 shows the overall block diagram of the system. Two IMU sensors are directly corrected to the Arduino UNO mainboard, which is plugged to a computer.

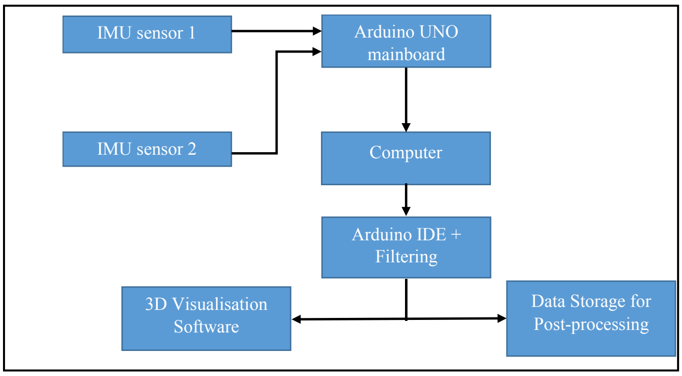


Fig. 1. The overall block diagram of the system

B. Sensor

In sensing the human limb movements, two gyroscope/ accelerometer sensors (MPU-6050) are used. The MPU-6050 is not expensive, especially given the fact that it combines both an accelerometer and a gyroscope. Since two of these sensors will be strapped on the upper and lower arm of the user, the rotation along the x, y, and z axis of the user's upper arm and lower arm will be tracked.

In the MPU-6050, there is an onboard chip called the DMP (Digital Motion Processor) which can be programmed to filter and process the raw values obtained from the sensor; the 3-axis acceleration and the 3-axis gyro values into readable and stable output.

After capturing the orientation of the limb, the data is then exported to a virtual 3D environment to act as an input for a 3D model of a human limb consisting of the upper and lower arm which can duplicate the movement of the user's limb motion. At the same time, the motion of the user's limb will be stored as data to be used for post-processing purposes. These stored data can be applied with the kinematics of the human limb to further analyze the position of the user's limb at that time using Microsoft Excel.

C. The prototype

The completed prototype consists of several components that were wired and assembled together to achieve a workable and functional system. Figure 2 shows the fully assembled prototype.

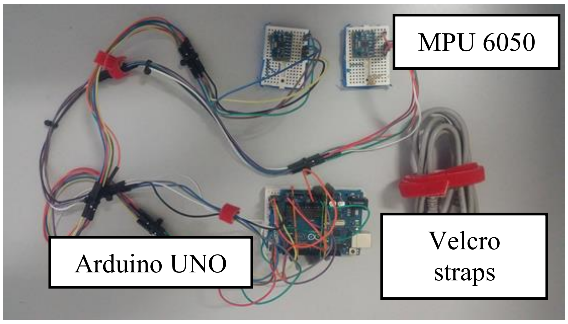


Fig. 2. The prototype

The prototype costed only USD 36. The most expensive component was the Arduino UNO microcontroller followed by the two sensors. Table 2 shows the breakdown of the cost for each components.

TABLE II. LIST OF COMPONENTS USED IN THE PROTOTYPE

Component	Quantity	Cost[a] (USD)
MPU-6050 sensors	2 units	9.00
Arduino UNO	1 unit	11.25
Protoboard	3 units	7.50
Electronics components, cables, connectors, wires and Velcro straps	1 set	8.25
	Total	36.00

[b] The cost is based on the local purchase and conversion rate at the time of writing

Figure 3 shows how the sensors are mounted to a human arm. One of the sensor was strapped at the upper limb of the arm above the elbow, while the other sensor was strapped at the lower part nearby the wrist.

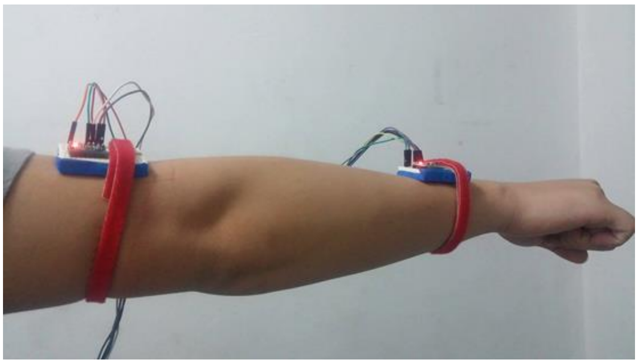


Fig. 3. The sensors attachment to the arm

D. The software

The software used to read the angles from the sensor is Arduino IDE 1.6.5 while the software used to construct and visualize the motion of the human arm is Processing 2.2.1. In this project, DMP (Digital Motion Processor) which is embedded in the MPU-6050 chip provides an advantage to obtain stable angle values from the sensor.

In order to obtain values using the DMP, specific codes will be used for coding in Arduino IDE. A sketch of codes has been written to take advantage of the DMP available on the chip and to obtain the sensor angle values. The DMP sketch offers two options that can have two outputs. The first one is the display of angles in terms of Euler angles which is the orientation angles along the x, y and z axis. The angles are displayed in the serial monitor and have a range of -180 degrees to 180 degrees for each rotation axis which represents the yaw, pitch and roll angles.

The display is projected in an 800x800 pixels window using OpenGL graphics. Processing was used to display the orientation of two sensors which represents the motion of the human limb which shows the yaw, roll and pitch movements. Figure 4 shows an example of Processing screenshot.

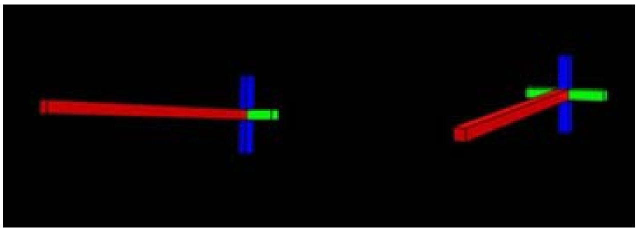
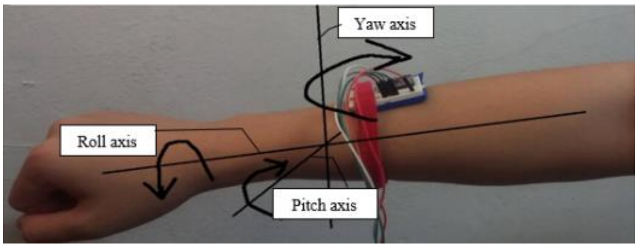


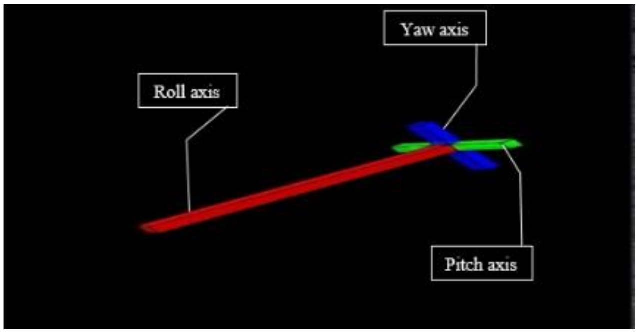
Fig. 4. Example of a screenshot from Processing

IV. Result and Discussion

After the prototype was fully constructed, several tests were carried out to determine its accuracy and percentage error in terms of reading the angle values. The representation of the human limb in Processing were also compared to the real limb to determine its likeness according to real motion of the human limb. Figure 5a shows the how the sensor is strapped to the arm with the assumption of yaw, pitch and roll convention, while Figure 5b shows the orientation in the virtual world.



(a)



(b)

Fig. 5. The experiment set-up and the orientaion of yaw, pitch and roll

A test was carried out by rotating the limb in yaw plane, roll plane and pitch plane. The limb was rotated by an increment of 10 degrees. As the limb rotates, the values obtained in the serial monitor were recorded and tabulated. Then, the percentage error was calculated to determine its accuracy of each measurement. The test was carried out three times to get a more accurate and averaged results.

Tables 3 shows partial results of the first test. The results show the recorded measurement of the sensor when rotated on yaw plane, roll plane and pitch plane. After the measurements were recorded, the recorded values were compared with the real angle thus obtaining the percentage error at each recorded angles at an increment of 10 degrees. In the first test result, the highest percentage error is at 8.1% at 10 degrees while the lowest percentage error is at 0.04%.

TABLE III. Partial Result from the First Test

Real angle (°)	Yaw		Roll		Pitch	
	Sensor (°)	*% error*	*Sensor (°)*	*% error*	*Sensor (°)*	*% error*
0	0	0	0	0	0	0
10	10.81	8.10	9.57	4.30	10.73	7.30
20	21.31	6.55	20.84	4.20	21.25	6.25
30	31.68	5.60	31.87	6.23	31.95	6.50
40	42.55	6.37	41.77	4.43	42.33	5.83

Real angle (º)	Yaw		Roll		Pitch	
	Sensor (º)	*% error*	*Sensor (º)*	*% error*	*Sensor (º)*	*% error*
50	50.16	0.32	50.90	1.80	50.70	1.40
60	59.34	1.10	61.53	2.55	60.61	1.02
70	70.54	0.77	70.11	0.16	70.50	0.71
80	81.98	2.48	79.56	0.55	80.94	1.18
90	91.34	1.49	91.32	1.47	91.50	1.67

In the second test result, the highest percentage error is at 7.6% while the lowest percentage error is at 0.09%. In the third test result, the highest percentage error is at 6.8% while the lowest percentage error is at 0.13%. Figures 6, 7 and 8 show the graph of real angles against measured angles and also the graph of real angles against percentage error for the first, second and third time of test results of the sensor.

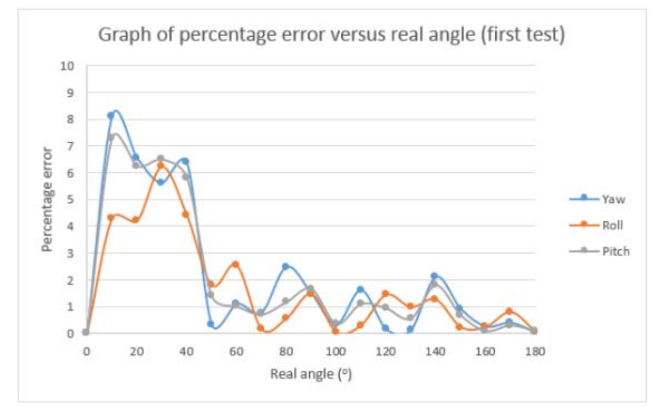


Fig. 6. Graph of the percentage error from the first test

Based on all the tests conducted, the average value of the percentage error can be calculated and the highest percentage error is 6.43% while the lowest percentage error is 0.20%. It can be observed that the highest percentage error usually occurs at the yaw plane. This suggests that the MPU-6050 has a lower accuracy in measuring yaw. This might be due to the lack of magnetometer in the sensor which is meant for measuring yaw rotation.

However, the MPU-6050 can still be considered to perform well in measuring yaw as it takes advantage of the DMP which is embedded in the sensor itself as DMP performs complex calculation to obtain the yaw angle values from the acceleration and gyroscopic values from pitch and roll movement. Since the highest percentage error is less than 10%, the MPU-6050 can be considered to be within acceptable accuracy range thus validating the effectiveness of using MPU-6050 to measure the rotation of a human limb at its axis.

V. Conclusion

The main aim of this work is to develop a low cost system that can be used to track upper human limb motion. The developed system uses two inertial measurement unit based sensor, the MPU-6050, to detect and capture the position of the limb when it is moving. An Arduino Uno microcontroller is used to control the whole system. The data is sent to a personal computer to be displayed visually on the screen in real time. These data ware also saved for further post processing.

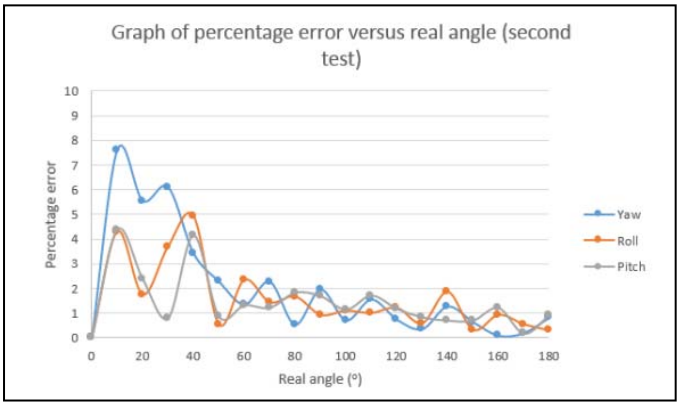


Fig. 7. Graph of the percentage error from the second test

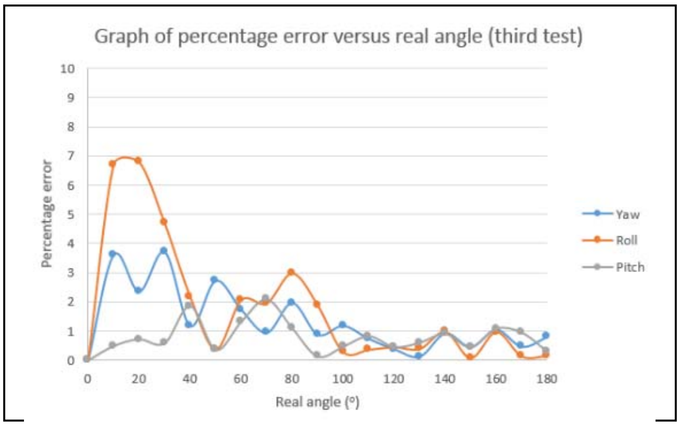


Fig. 8. Graph of the percentage error from the third test

Using these components, the overall cost of the prototype was USD 36 only, fulfilling the main aim of the project. From the test carried out using the prototype, the result was very promising, with satisfactory accuracy and repeatability.

It is acknowledged that there is still a lot of rooms for improvement in getting better accuracy and reliability, as well as making the mounting strap more comfortable to the person. These improvements are currently in progress to improve the system while retaining the cost to be as minimum as possible.

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