Implementation of IMU Sensor for Elbow Movement Measurement of Badminton Players

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***Abstract* —This paper gives an insight on the design and development of a mobile measurement device to measure the elbow joint movement of a Badminton player. Badminton is one of the fastest racket-based sport. Since a human eye alone is not capable of capturing all these fast movements the usage of high processing optometric system became a popularity but the downside is these systems are expensive and large in size. The proposed solution is to develop a reasonably cheap and small size mobile measurement device utilizing the miniature sensor technology which can perform the task capturing the badminton player's movements just as an optometric system will do. This proposed device will use the MPU6050 IMU unit to measure the rotational angle of the elbow joint where the data fusion between the accelerometer and gyro will be performed by the inboard MPU6050 DMP. Experiments were conducted to verify the reliability and feasibility of IMU sensor towards the design of this proposed measurement device. The experiments result shows promising results of the usability of the IMU sensor in measuring the rotational angle of the players elbow joint.**

Keywords — MPU6050, Kinematics, Accelerometer, Inertia Measurement Unit, Badminton, Elbow Measurement

I. INTRODUCTION

Badminton is a game in which two opponent's battle in hitting the shuttlecock to gain points against each other. Badminton also can be considered as one of the fasters racket-based sports as it involves mostly fast and dynamic movement [1]. After many years of being played through the world, badminton has evolved to be a very popular sports [2] and also can be considered as the top growing game played in Malaysia.

In a badminton game, players need to be alert of the tactics and the amount of energy they use in order to be able to perform well. However, scientific study on tactics, strategy, or playing patterns of international level badminton are very limited [3]. This study aims to profile individual badminton player's movement when they perform a certain badminton moves and to establish a comprehensive database of the player's badminton tactics. The process of continual measurement and evaluation is essential for players as it helps them to analysis their own performance to be motivated to do better [4].

Since badminton is a fast paced game, some movements of the player are certainly overwhelming for the human eyes. For this, some researchers recommend the usage of vision systems that consist of markers and cameras. Roxana et al. [5] have used 9 infra-red emitting cameras to capture the movement of a cricket player's arm during bowling and throughout the game. Usually, high dynamics movements are analysed by using high-speed optometric systems consisting of high capture rate cameras [1]. However, due to some technical limitations (e.g. high amount of light) that exist when using this method in the stadiums, these measurements are often performed in a laboratory setting [6]. This condition does not comply well with the real competition or training conditions [7] and the usage of optometric systems is expensive while requires high-speed equipment to operate.

Although vision system has been used widely to analysis players movement, but there is a new promising method of using miniature sensors. The technology of miniature sensors allows high sample rate data collection and a wide measuring range when connected to a microcontroller [8]. Thus, the best method available to be able to successfully capture the badminton player's data while still offering flexibility and keeping the low cost for training purposes will be wearable sensors. Wearable sensors have been used in many fields to measure human movement and dynamics, where it can also be used to monitor the kinematic aspects of performance. To be able to monitor this in a natural way there is a need for integrated sensors that are easy to use, comfortable and is wearable [6]. Thus this paper presents a method of using inertial measurement units (IMU's) to record the movement of the badminton players elbow movement during few types of movement.

II. KINEMATIC MODEL OF THE ELBOW

Determining the kinematic model of the elbow is important because the elbow functions mainly as a link in the kinetic chain allowing the transfer of kinetic energy from the body to the racquet. Kinematics is used to describe motion without consideration given to its mass or the forces acting on it [9]. Decades of technology has been implemented into developing sports clothing for athletes that can be used to capture the kinematics of an athlete. This feedback information is important for both the athlete and the coach to raise body awareness which may help to improve playing technique.

The human elbow is one unique joint which consists of two basic parts, upper arm, and lower arm portions. The upper arm portion, located above the elbow joint consist of one single bone called the Humerus bone. While the lower portion of the arm which is below the elbow joint consists of two bones, the Radius bone and the Ulna bone as illustrated in Figure 1 [10]. The elbow is made up of two type of joints, one is the hinge joint between the Humerus and Ulna bones called the Humeroulnar joint and the second is the ball-socket joint between the Humerus bone and Radial bone called the Humeroradial joint are shown in Figure 1.

Figure 1. Human elbow skeleton [10]

The structure of the arm allows a human to perform four basic movements using the elbow joint, namely arm flexion, arm extension, pronation and supination [11], these movements are shown in Figure 2. The human arm in total has 7 Degree of Freedom (DOF), the elbow contributes to 1 DOF by enabling a human to move their lower arm portion up and down.

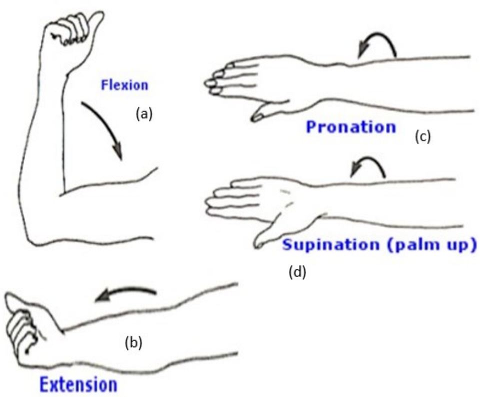

Figure 2. Type of Movement based on elbow joint [11]

III. HAND MOVEMENT AND MOTION MEASUREMENT METHOD

Referring to previous studies, this paper conducts study on the method used to read and analysis the movement and position of the badminton player's elbow during training. Studies conducted regarding measuring the player's movement using IMU's are, however very limited as most of the studies focus on the shuttle speed instead of the movement itself. Thus, methods of measuring elbow movement are adopted from other fields like Biomedical engineering [5], [12], [13], [14] and sport injuries predictions .

Andrea et al. [15] develop a new protocol using IMU sensors to measure elbow and shoulder movement in ambulatory settings. By analysing and studying the kinematic model and parameter used in this paper the placement of the IMU sensor is determined, which is just below the elbow joint facing the wrist.

Another researcher, Wei et al. [16] has chosen to use inertial measurement units over the usage of optoelectronic or electromagnetic systems to calculate the rotation axis and the elbow angles which uses the Product of Exponential (POE). Meanwhile, Ryan et al. [17] has two IMU sensors to test the mobility of the elbow joint motion when a person is inside the Contingency Hypobaric Astronaut Protective Suit (CHAPS). This analysis of the previous work strongly suggests that IMU sensors have been widely used in many fields to measure human movements.

The maximum Range of Motion (ROM) for a human's elbow is between 140˚ to 150˚ for flexion [11] and 0˚ for an extension [11] depending on the health condition of the player, some manage to perform extension up to 10˚ in which this condition is called Hyperextension due to joints flexibility. The orientations of the elbow that will be tested are shown in Figure 3.

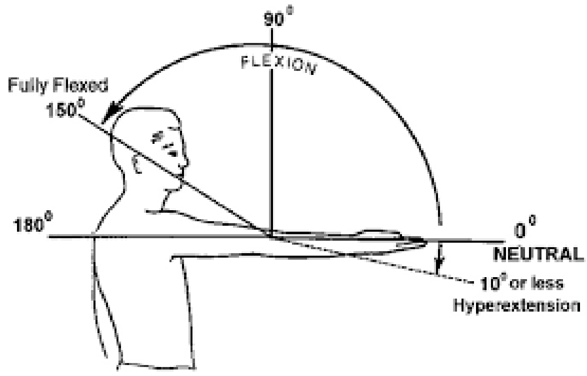

Figure 3. The Range Of Motion of the Human Elbow [11]

A. Hardware Configuration

The main intention of this research is to develop a functional and user-friendly device which can be used to measure the rotational and angle of the player's elbow joint. Figure 4 and Figure 5 shows the overall hardware setup of the developed system. The main sensor, MPU6050, which is a six-axis MEMS motion tracking IMU from InvenSense [18] is used to measure the rotational angle of the player's elbow. Secondly, is the microcontroller, Arduino Nano [19] is used to process the IMU data, this is where the accelerometer and gyroscope data is fused by the coded algorithm and the recorded data is then send to the PC using Bluetooth. Next is the HC-05 Bluetooth module by ITeadStudio [20], which has been configured as master using 38400 baud rate for sensor data transmission [21]. Finally is the notebook which records and logs the data received into a text file to be analysed.

Figure 4. The developed pouch bag for sensor housing.

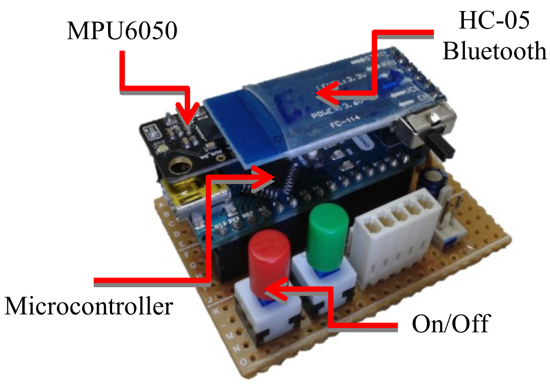

Figure 5. The configuration of the MPU6050 sensor.

B. *Software Configuration*

The data acquisition algorithm for the MPU 6050 is written in C language using the Arduino IDE software, which is free and open source. The data acquisition algorithm used to obtain data from the MPU6050 converts the raw data obtained from the sensor into Euler angles. One important part of high-speed data acquisition is data sync between the transmitter and receiver for this setting of the data transmitting rate (baud rate) should be the same for all device. For this project the initial testing baud rate used was 9600, once the reading of data stabilised the baud rate was increased gradually to 38400. This baud rate was selected based on the time taken for the buffer programmed into the controller to overflow.

IV. RESULTS AND DISCUSSION

Reviews on previous works done using the IMU is used to construct an outline for the experimental setup to test the capability of the MPU 6050 to measure the rotational angle of the badminton player. To conduct this test five healthy right-handed badminton player aged from 24 – 26 years old were asked to volunteer. Then each of the badminton players is asked to strap on the elbow cap as shown in Figure 6 to their elbow, which has an IMU sensor integrated into it and perform the 4 basic movements referring to Figure 2. The data obtained from the IMU sensor is recorded and logged which later will be used for further comparing and analysis. The two type of movement mentioned in Figure 3 will be tested individually by measuring the orientation (z, y, and x), where blue represents the z-axis, green represents the y-axis and red represent the x-axis and also the angle (Euler angle) of the elbow is measured.

A. *Elbow Extension Results*

The maximum range of movement for an extension of the elbow is between 0° - 10°. For this test the players are asked to place their hands flat on a table's edge and tilts their hand as far down as possible as shown in Figure 6, the movement data was recorded and tabulated in Table 1. The results are able to indicate that the IMU sensor is able to detect the hyperextension by a maximum of 58% detection accuracy which has a maximum range of 10°. The hyperextension condition might cause elbow injuries if persistent for a long period of time.

Figure 6. Hand movement illustrating hyperextension

Table 1: Elbow extension measurement at range 0° to -10°

Players	Actual Angle	Measured Angle (Mean)
Player 1	0° to -10°	**- 4.18°**
Player 2		**- 5.39°**
Player 3		**- 6.20°**
Player 4		**- 5.56°**
Player 5		**- 6.12°**

B. *Elbow Flexion Results*

The maximum range of movement for a flexion of the elbow is between 0° to 140° or 150°. So for this test, a few different angles will be tested which are 0°, 45°, 90°, 150°. To conduct this test the players are asked to stands upright placing their hands out in front and bend their hands as far as possible as shown in Figure 7, the data was recorded and inserted into Table 2, Table 3, Table 4 and Table 5.

Figure 7. Hand movement for 0°

Table 2: Elbow flexion measurement at 0°

Players	Actual Angle	Measured Angle (Mean)
Player 1	0°	**1.01°**
Player 2		**1.00°**
Player 3		**0.98°**
Player 4		**0.98°**
Player 5		**0.98°**

The result in Table 2 indicates the IMU is capable of reading the angle of the player's hand at 0° or at rest. The sensitivity of the MPU 6050 sensor is considered high since it is able to detect the small movements made by the players although the players place their hands straight in front and the reading should be 0˚. But this is not possible in real world conditions as the hand tend to move and is not stiff, this slight variation in the reading is also caused by the integration error that accumulated over time but this error is taken care by the Digital Motion Processing unit onboard the MPU6050 sensor.

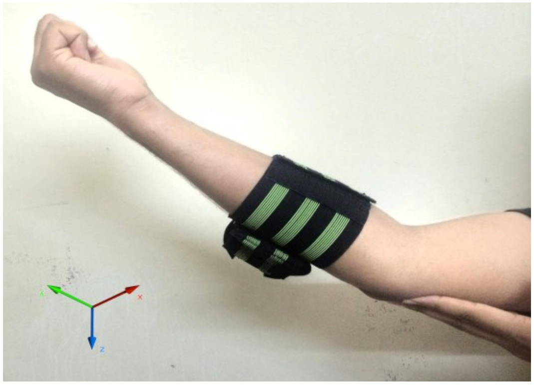

Figure 8. Hand movement for 45°

Table 3: Elbow flexion measurement at 45°

Players	Actual Angle	Measured Angle (Mean)	Error (%)
Player 1	45°	**42.09°**	6.46
Player 2		**42.78°**	4.93
Player 3		**43.37°**	3.62
Player 4		**44.14°**	1.91
Player 5		**44.74°**	0.57

Table 3 shows the results when the player starts to bend his hand toward the body, this orientation can be seen in Figure 8. The shift in angle is from 0° to 45° as the player lifts his hand. The sensor is able to measure the movement with error as little as 6 %.

Figure 9. Hand movement for 90°

Table 4: Elbow flexion measurement at 90°

Players	Actual Angle	Measured Angle (Mean)	Error (%)
Player 1	90°	**88.72°**	1.42
Player 2		**88.90°**	1.22
Player 3		**89.07°**	1.03
Player 4		**89.21°**	0.87
Player 5		**89.38°**	0.68

Table 4 shows that the IMU sensor is capable of detecting the correct angle when the player lifts his hand and place it at a 90° angle against the x-axis and aligning the hand to 0° on the z-axis with the palm facing the face as shown in Figure 9. The readings of the IMU sensor is acceptable with an error just near to 2 %.

Figure 10. Hand movement for 150°

Table 5: Elbow flexion measurement at 150°

Players	Actual Angle	Measured Angle (Mean)	Error (%)
Player 1	150°	**144.92°**	3.38
Player 2		**144.90°**	3.40
Player 3		**144.95°**	3.36
Player 4		**145.00°**	3.33
Player 5		**145.01°**	3.32

Table 5 shows the IMU sensor reading when the player bends his hand from straight until as far as the player can bend his hands which are from 0˚ to 150˚, this orientation can be seen in Figure 10. The angle changes in X-axis can be seen from the data in Table 5 which show a positive value since the movement of the player's hand is in the positive region of the gyroscope. The maximum error obtained is around 3.40% which may be due to the rounding error caused by adding previously saved angle to the current obtained angle. Figure 11 show the line graph of tabulated data for player 3. This graph shows very little deviation between the ideal and measured angle, this suggests that the developed measuring device is ideal to be used for this research.

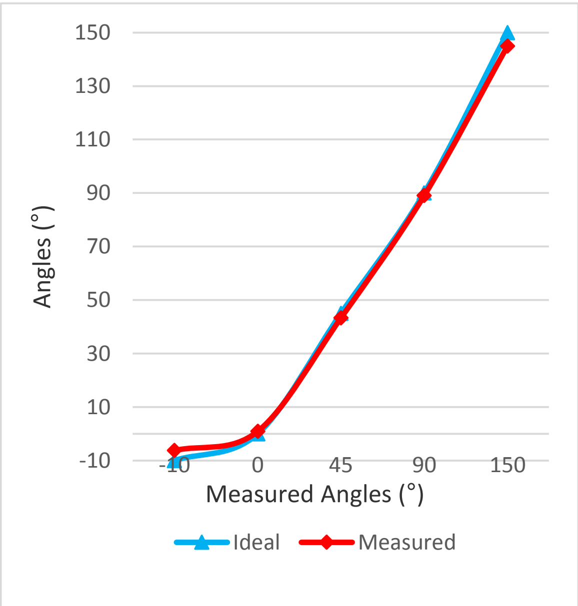

Figure 11. Movement Data for Player 3

V. CONCLUSION

The aim of this paper is to develop a hardware that is capable of recording the rotational movement of a badminton player's elbow, for this a proposed system has been developed and was tested. The results suggest that there are needs for more data refining in term of code structure and the IMU data management before it can be used as a reliable device to be worn by the player. The evaluation using the developed prototype in real hardware experiment showed a good and promising performance and the capability of IMU sensor to provide a reliable way to measure the rotational angles and is proven possible.

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REFERENCES

[1] A. Jacob, W. N. W. Zakaria, and M. R. B. M. Tomari, 'Quantitative Analysis of Hand Movement in Badminton', in *Lecture Notes in Electrical Engineering*, vol. 362, H. A. Sulaiman, M. A. Othman, M. F. I. Othman, Y. A. Rahim, and N. C. Pee, Eds. Phuket: Springer International Publishing, 2016, pp. 439–448.

[2] N. Yang, 'Research of badminton forehand smash technology based on biomechanical analysis', *Journal of Chemical and Pharmaceutical Research*, vol. 5, no. 11, pp. 172–177, 2013.

[3] Y.-M. Tong and Y. Hong, 'The playing pattern of world's top single badminton players', *18 International Symposium on Biomechanics in Sports*, pp. 1–6, 2000.

[4] J. R. Morrow, A. W. Jackson, and J. G. Disch, *Measurement and Evaluation in Human Performance*, 4th ed. Human Kinetics, 2011.

[5] R. Montazerian, A. Shaheen, T. Eftaxiopoulou, and A. M. Bull, '3-D Elbow Kinematics During Cricket Bowling', *Journal of Biomechanics*, vol. 41, no. July, p. S85, 2008.

[6] D. Morris, S. Coyle, K.-T. Lau, D. Diamond, and N. Moyna, 'Textile-Based Wearable Sensors for Assisting Sports Performance', *2009 Sixth International Workshop on Wearable and Implantable Body Sensor Networks*, pp. 307–311, Jun. 2009.

[7] T. Jaitner and W. Gawin, 'A mobile measure device for the analysis of highly dynamic movement techniques', *Procedia Engineering*, vol. 2, no. 2, pp. 3005–3010, 2010.

[8] T. Jaitner and W. Gawin, 'Analysis of Badminton Smash With a Mobile Measure Device Based on Accelerometry', *XXV ISBS Symposium, Ouro Preto, Brazil*, pp. 282–284, 2007.

[9] Vladimir M Zatsiorsky, *Kinematics of human motion*, 1st ed. 1998.

[10] M. Walden, 'Elbow Anatomy - Sports Injury Clinic'. [Online]. Available: http://www.sportsinjuryclinic.net/anatomy/elbow-anatomy. [Accessed: 24-Apr-2016].

[11] C. C. Norkin and D. J. White, *Measurement of Joint Motion: A Guide to Goniometry*. F.A. Davis, 2009.

[12] T. Liu, Y. Inoue, K. Shibata, and R. Zheng, 'Measurement of human lower limb orientations and ground reaction forces using wearable sensor systems', *2007 IEEE/ASME international conference on advanced intelligent mechatronics*, pp. 1–6, 2007.

[13] K. Shirota, K. Watanabe, and Y. Kurihara, 'Measurement and analysis of golf swing using 3-D acceleration and gyro sensor', *Proceedings of the Society of Instrument and Control Engineers Conference*, pp. 356–360, 2012.

[14] C. T. Kiang, C. K. Yoong, and A. C. Spowage, 'Local sensor system for badminton smash analysis', in *2009 IEEE Intrumentation and Measurement Technology Conference, I2MTC 2009*, 2009, no. May, pp. 889–894.

[15] A. G. Cutti, A. Giovanardi, L. Rocchi, A. Davalli, and R. Sacchetti, ‘Ambulatory measurement of shoulder and elbow kinematics through inertial and magnetic sensors’, *Medical and Biological Engineering and Computing*, vol. 46, no. 2, pp. 169–178, 2008.

[16] W. S. Ang, I.-M. Chen, and Q. Yuan, ‘Ambulatory measurement of elbow kinematics using inertial measurement units’, *2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics: Mechatronics for Human Wellbeing, AIM 2013*, pp. 756–761, 2013.

[17] C. E. Carr, F. Meyen, A. R. Domingues, P. D. J. Newman, S. E. Jacobs, and D. C. Company, ‘Using inertial measurement units for measuring spacesuit mobility and work envelope capacity for intravehicular and ex’, *63rd International Astronautical Congress*, pp. 1–9, 2012.

[18] InvenSense, ‘MPU-6050 | InvenSense’. [Online]. Available: http://www.invensense.com/products/motion-tracking/6-axis/mpu-6050/#. [Accessed: 25-Apr-2016].

[19] Arduino, ‘Arduino - Arduino Board Nano’, *Arduino*, 2007. [Online]. Available: https://www.arduino.cc/en/Main/ArduinoBoardNano. [Accessed: 25-Apr-2016].

[20] ITeadStudio, ‘HC-05 - Serial Port Bluetooth Module (Master/Slave)’. [Online]. Available: http://wiki.iteadstudio.com/Serial_Port_Bluetooth_Module_(Master/Slave)_:_HC-05. [Accessed: 25-Apr-2016].

[21] A. Jacob, W. N. W. Zakaria, and M. R. B. M. Tomari, ‘Implementation of Bluetooth Communication in Developing a Mobile Measuring Device To Measure Human Finger Movement’, *ARPN Journal of Engineering and Applied Sciences*, vol. 10, no. 19, pp. 8520–8524, 2015.