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Development of wrist monitoring device to measure wrist range of motion

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Abstract. Study of human motion has been paying attention. From manual goniometer which consists of moving arm and a protector to assess the range of motion had been developed into equipment with strain gauge, flex sensor and many more. In recent years, the advance of microelectromechanical systems (MEMS) has boosted the use of inertia measurement unit (IMU). MPU 6050 is one of the IMU used in this study to assess wrist range of motion. Algorithm using Arduino has developed to improve the accuracy. A Bluetooth module is used to communicate with smartphone. An android application is developed to display data on smartphone. The device is tested to validate the reliability of measuring wrist range of motion. First test is carried out to test for the stability of each axis at 300, 600 and 900. For roll axis (counter-clockwise) and pitch axis (counter-clockwise) shows fluctuation. The other axis show slightly fluctuation. When tested on human wrist, the device able to give error in the range of 10 – 50. The result from device is compared with manual goniometer performed by physiotherapist. Placement of device o back of hand may affect the result. Front spot, middle spot and end spot placement has been tested to see the relationship. From testing, middle spot and end spot show better result compare to front spot. In performing radial deviation and ulnar deviation, end spot show significant closer result. However, this placement restricts the movement of wrist. Middle spot give overall close result.

Keywords. Goniometer; Wrist; Range of motion; MPU 6050; Android apps.

1. Introduction
Device to monitor or to measure range of motion (ROM) of joints is generally referred to as "goniometry". The term, "goniometry" is derived from two Greek words, "gonia", meaning angle and the word "metron", meaning measure [1]. Therefore, goniometry refers to the measurement of degree of angle of rotation at joints of bones. In early 1900s, goniometer had been a common device developed to measure range of motion in France [2]. During world war, the goniometer is widely used to treat injured soldiers returned from war [3] and nowadays, mostly used in hospital and rehabilitation center [4].

Analysis on joint motion of human body parts is an important area in the medical field. It is crucial where analysis if often required for medical diagnosis and physiotherapy. In 2010, 37% of industrial accident cases was reported by the Instituto Mexicano del Seguro Social (IMSS) [5]. The Instituto

Nacional de Rehabilitacion (INR) stated that most of the hand surgeries represented 18.45% of all orthopaedic surgeries performed in 2010 while the injuries are normally involved the dominant hand.

Device for joint range of motion assessment currently in clinical setup is the manual goniometer. It consists of one stationary arm and one moving arm at axis or fulcrum of the protractor. This device is not only tedious but also time consuming [6]. More researchers are developing electrogoniometer to assess the range of motion of joint which is described in a patent [7]. However, these electrogoniometer possess crosstalk errors which may influence the result [8]. Currently there are many researches ongoing to improve goniometry which includes using smartphones [9] goniometer reliability [10], fiber optic gyroscope goniometer [11], wall goniometer [12], knee smartphone-application goniometer [13] and vertical dual-axis goniometer [14].

The aim of this study is to develop a portable and compact device to assess the wrist range of motion. The MPU 6050 is used in this study for the assessment. It is also aimed to evaluate the reliability of the device on the wrist range of motion.

2. Methodology

2.1. Casing design
A casing is designed (figure 1.) to fit five components including inertia measurement unit (MPU 6050), Bluetooth device (HC-06), lithium cell charger (FC-96), Arduino pro mini and a lithium cell. SolidWorks software is used to design the casing. The design of the casing is made in a compact size for portability. Unlike other goniometer which are big in size and is not portable. This device for this study is made as compact as possible to achieve a good portability.
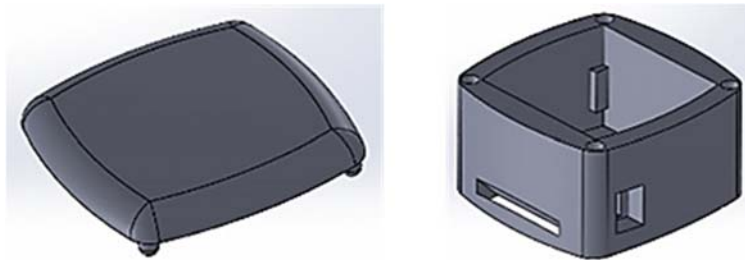

Figure 1. Casing Design. Cover (left) and case (right).

The casing dimension is 50 mm x 50 mm x 35 mm, width, wide, height respectively. A hole is made for USB plug cable to plug in the lithium cell charger when charging. Opposite two end at the bottom of casing is to put hook and loop tape. The purpose of using hook and loop tape is to hold tightly the casing to the hand. This type of tape is also easy to be used. The model design is sent to 3D printer to print out the casing.

2.2. Hardware design
The device consists of Arduino pro mini, Bluetooth module, lithium battery and charger and MPU 6050 sensor. All the components are powered up by the 3.7V rechargeable lithium battery. The charger is used to charge the lithium battery when run out of power. Arduino pro mini connects the MPU 5050 and the Bluetooth module for the whole system to function. The Bluetooth module is to establish a wireless connection to phone. The data from the sensor will be transmitting to phone through the android application. The connection of all the components are designed in breadboard first before proceeding to soldering (figure 2.). After testing the circuit, the circuit is soldered and assembled into the casing (figure 3).
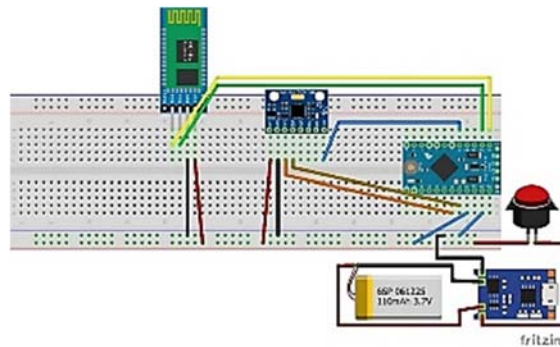
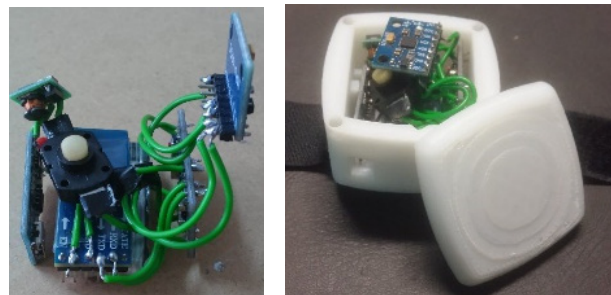**Figure 2.** Schematic diagram of device connection.

Figure 3. Wrist measurement device. Circuit of components (left)
and Casing assembly (right).

2.3. Software design

An android application will be developed by using Massachusetts Institute of Technology (MIT) App Inventor. It is a platform using code blocks to create software application for android operating system. This software application is used to communicate with Arduino through the Bluetooth module. The software application has the option to choose which type of measurement to assess wrist range of motion. The MPU 6050 will then send data of angle to display on the smartphone's screen. Two android applications are build, one is for user and one is for developer (figure 4).
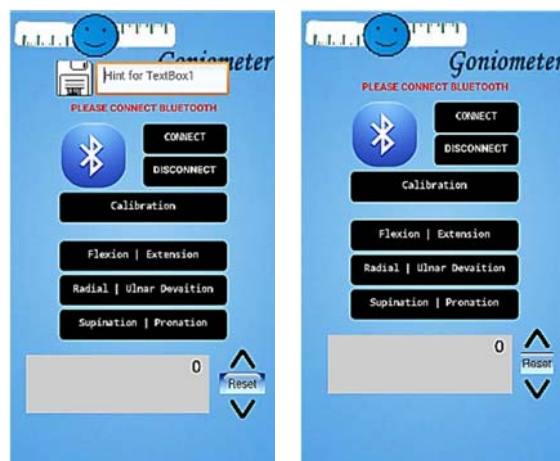

Figure 4. The android application display on the left is to display the data send from MPU 6050 while the android application on the right is used to collect any data send from MPU 6050.

2.4. Wrist posture measurement
The device is designed as the function of manual goniometer to measure wrist range of motion. The device is placed on the back of the hand with the help of hook and loop tape. There are six measurement of wrist range of motion such as flexion, extension, supination, pronation, radial deviation and ulnar deviation (figure 5). To validate the reliability of this device, the data from the device will be compared to the data from manual goniometer.
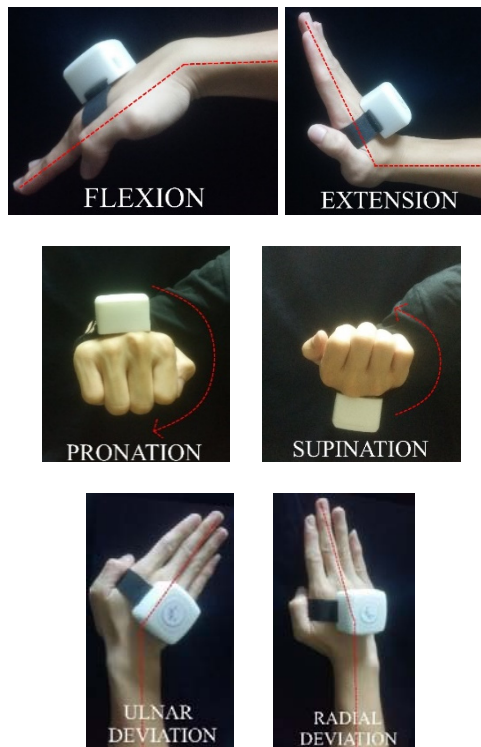

Figure 5. Wrist range of motion measurement.

3. Results
The testing is divided and carried out into three different sections. In section one, the device is placed on a flat surface and is allowed to turn on. The device is then rotated to certain selected angles for the testing. Selected angles for testing are 30^0, 60^0 and 90^0 are measured for validating the reliability of the wrist measurement device. Second section of the test is to place the wrist measurement device on the back of the hand of subjects. The subjects are to move his or her wrist in flexion, extension, supination, pronation, radial deviation and ulnar deviation. A physiotherapist from Pusat Kesihatan Pekan at Universiti Malaysia Pahang (UMP), is to perform the measurement using manual goniometer. The result from both manual goniometer and wrist measurement device will be compared to validate whether the device is reliable or not. Third section of the test is to place the device on different spots on back of the hand. Front spot, middle spot and end spot placement are to be tested. This test is to investigate the difference in result of the three different spot placement regarding the stability of device test.

Self-test is performed to see the behaviour of the result of the device. Six measurement – flexion, extension, supination, supination, radial deviation and ulnar deviation, are taken into measurement. The measurement test involved three angles which are 30^0, 60^0 and 90^0. This test is performed to determine whether when repeated same position of motion, the device able to give consistent data. An android application which can store the data from the wrist measurement device to smartphone storage is built for this purpose of testing.

3.1. Subject measurement test

Two subjects are tested with the wrist measurement device for validating the reliability of the device. To compare the result, manual goniometer is used as the standard of measurement. Physiotherapist form Pusat Kesihatan Pekan at Universiti Malaysia Pahang (UMP), performed the measurement of wrist range of motion using the manual goniometer (figure 6). The wrist ranges of motion using manual goniometer by physiotherapist is compared with the data from device. The display on the smartphone in the android application will be looked as in figure 7.
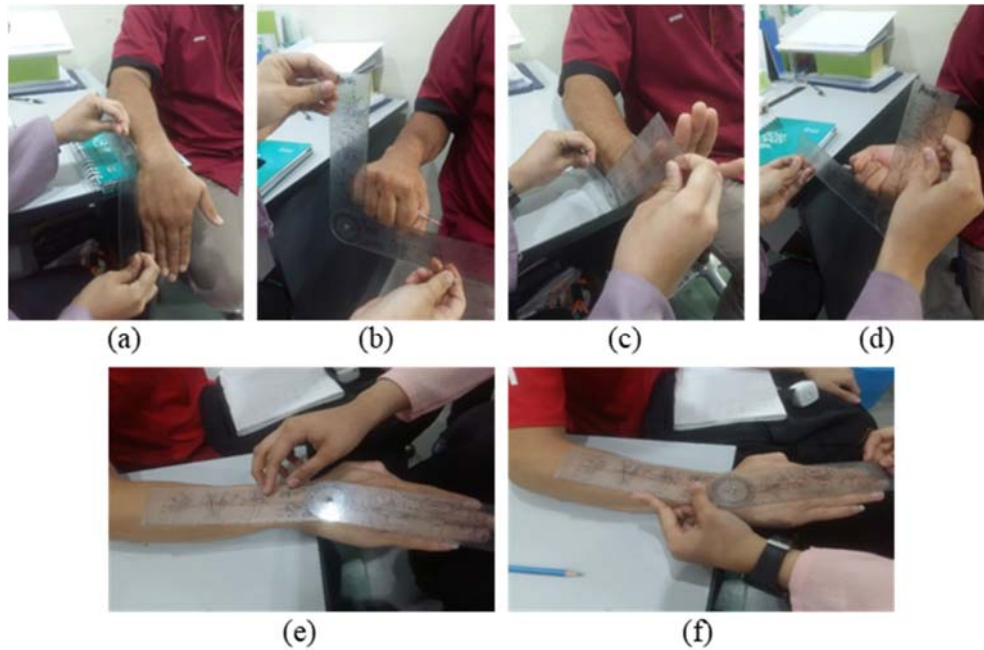

Figure 6. Wrist range of motion perform by physiotherapist (a) Extension, (b) Flexion, (c) Pronation, (d) Supination (e) Radial deviation and (f) Ulnar deviation.
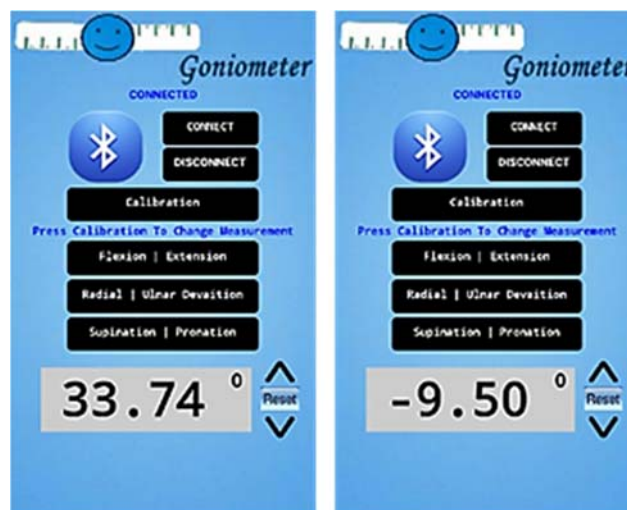

Figure 7. Data on android application display. Radial deviation (left) and flexion measurement (right).

4. DISCUSSION

4.1. Stability of device test

In figure 8, the trend of the graphs is quite similar and consistent for all the angles. The data angle 30^0 is slightly higher by range from 1.48^0 to 1.72^0. The data shows higher difference when for angle 90^0, by a difference around 5^0 less. However, in counter-clockwise, the graph fluctuation is significant as compared to clockwise. When angle measurement is increase to angle 90^0, the data seems to fluctuate more and inconsistent. The angle drops from 80^0 to 70^0 even with three times repeat of measure. The difference of around 10^0 of drop. Angle 60^0 to have higher 4 degrees for the first time and then nearly close to 60^0 by slight higher by 2 degrees. Angle 30^0 has the closer data with only difference by range from 0.5 to 0.75 degree.
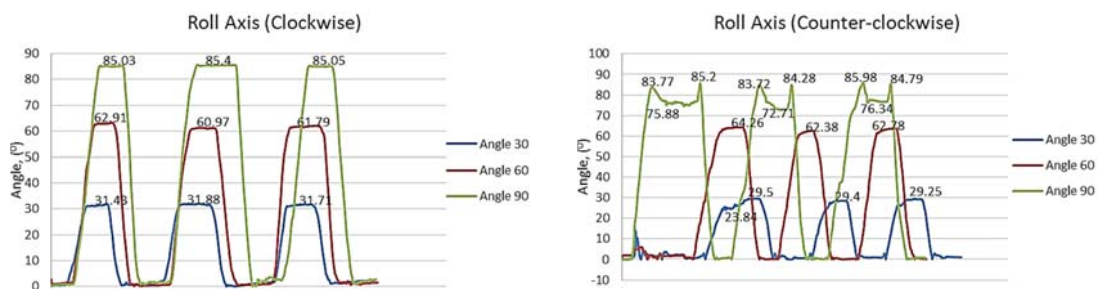

Figure 8. Behaviour of device at roll axis in clockwise (left) and in counter-clockwise (right) for angle 30^0, 60^0 and 90^0. The peaks of the graph show the values of selected angles to be measured. One peak means one repeat of measurement.

In figure 9, the high value of the angle appears to be the initial calibration has not completed. After a few seconds the data come back to almost zero offset. As like previous, the trend for lower angle graph are more consistent except for angle 30^0 in the first and second repeat. In the third repeat, the graph seems to be better. A difference angle of 3^0 to 4^0 for both the lower angle. For angle 90^0, the first repeat shows dropping of angle before consistent. With the device repeat a few times, it shows to be consistent again. However, the data obtained is way too far with a difference of 20^0 which is cannot be accepted. For data angle 30^0 and angle 60^0 is acceptable. While for counter-clockwise, angle 60^0 shows almost consistent and close to the value. Angle 30^0 also seems to almost consistent data but with difference of 2^0 to 3^0. Overall angle 60^0 and angle 30^0 show usable data. However, for angle 90^0, the data is fluctuating for the first and second repeat. It is constant when at the third repeat. For high angle such as 90^0, the data is unacceptable. The data is too much difference in degree. The data is consistently happened in roll axis and pitch axis.

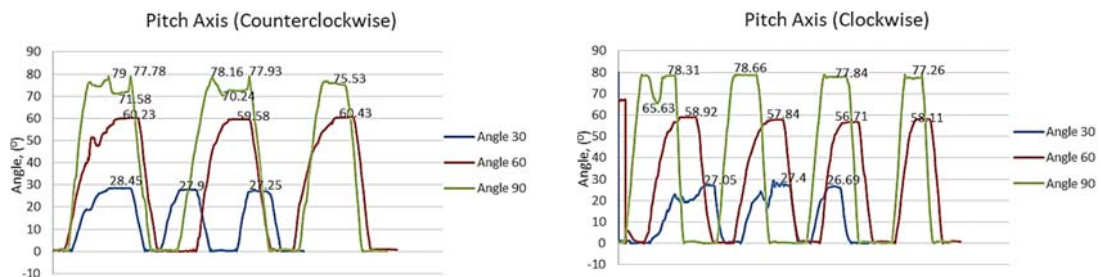**Figure 9.** Behaviour of device at pitch axis in clockwise (left) and in counter-clockwise (right) for angle 30^0, 60^0 and 90^0. The peaks of the graph show the values of selected angles to be measured. One peak means one repeat of measurement.

The initial calibration took more time in yaw axis as seen there are high values of data in figure 10. The data do not go down to zero offset. Manual calibration is used in the Android application to adjust the value to be zero offset. The data shows less error roughly 20 to 40 for angle 300. Angle 600 show consistent graph but only at the second repeat show significant drop of angle. Measurement of 90 degree shows quite a close result of difference 10 to 30 in yaw axis. For counter-clockwise, the calibration for initial data for yaw axis took longer time as in the yaw axis clockwise rotation. Manual calibration is needed to perform for better data. After manual calibrate, the 300 measurement shows better data that almost close to 300. For angle 900, the values are quite close as well. Overall for the three angle measurement show ± 30 which is acceptable as measurement.
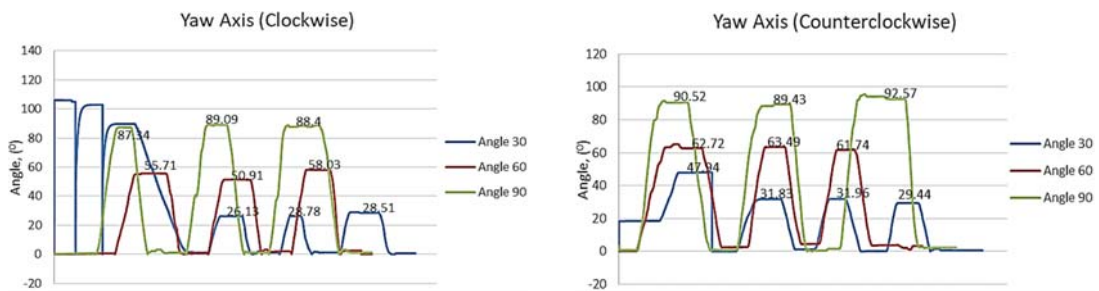

Figure 10. Behaviour of device at yaw axis in clockwise (left) and in counter-clockwise (right) for angle 30^0, 60^0 and 90^0. The peaks of the graph show the values of selected angles to be measured. One peak means one repeat of measurement.

4.2. Subject measurement test

The data from wrist measurement device are acceptable for both extension and flexion with around $\pm 1.00^0$ to 3.00^0 different from the manual goniometer. Extension measurement of the device are almost close to the manual goniometer only with a slightly higher by around 2^0 (table 1). However, in flexion measurement, the second subject shows unacceptable data, 65.21^0, which is very far away as compared to the manual goniometer data. From figure 6, the inconsistent and fluctuation graph of the roll axis in counter-clockwise making the data is not acceptable for measurement.

Table 1. Comparison between manual goniometer and wrist measurement device for extension and flexion.

Subjects	Extension (^{0})			Flexion (^{0})		
	Manual goniometer	Wrist measurement device	Tolerance	Manual goniometer	Wrist measurement device	Tolerance
Subject 1	$40^0 - 50^0$	51.64^0	$\pm 1.64^0$	35^0	33.74^0	$\pm 1.26^0$
Subject 2	$45^0 - 50^0$	52.56^0	$\pm 2.56^0$	$45^0 - 50^0$	65.21^0	$\pm 15.21^0$

Overall of the supination and pronation data from the wrist measurement device are acceptable for measurement. Surprisingly, the second subject, tolerance for supination and pronation are very small with only $\pm 0.66^0$ and $\pm 0.60^0$ respectively. However, the case is not applied to first subject. The data is not consistent as compared to first subject. Pronation measurement for first subject shows a very high tolerance of $\pm 15.81^0$ (table 2) which is totally unacceptable as measurement. In supination measurement, the device measures a value less than the manual goniometer as well.

Table 2. Comparison between manual goniometer and wrist measurement device for pronation and supination.

Subjects	Pronation (^{0})			Supination (^{0})		
	Manual goniometer	Wrist measurement device	Tolerance	Manual goniometer	Wrist measurement device	Tolerance
Subject 1	$45^0 - 50^0$	65.81^0	$\pm 15.81^0$	$50^0 - 55^0$	45.53^0	$\pm 4.47^0$
Subject 2	$70^0 - 100^0$	75.60^0	$\pm 0.60^0$	$70^0 - 80^0$	70.66^0	$\pm 0.66^0$

For subject one and subject two, both ulnar deviation and radial deviation shows almost close data as compared to the manual goniometer data (table 3). The lowest tolerance achieved only at $\pm 0.5^0$ while highest is $\pm 2.00^0$. This results are better as compared to flexion, extension, supination and pronation. But the data are acceptable except for the sudden high value that occur.

Table 3. Comparison between manual goniometer and wrist measurement device for radial deviation and ulnar deviation.

Subjects	Radial deviation (^{0})			Ulnar deviation (^{0})		
	Manual goniometer	Wrist measurement device	Tolerance	Manual goniometer	Wrist measurement device	Tolerance
Subject 1	10^0	9.50^0	$\pm 0.50^0$	$15^0 - 30^0$	31.70^0	$\pm 1.70^0$
Subject 2	$15^0 - 20^0$	18.00^0	$\pm 2.00^0$	$20^0 - 25^0$	25.46^0	$\pm 0.46^0$

4.3. Position of device test
During the testing, the device location of placement on the back of hand may affect the data. The data vary when the location of placement on the back of hand are different. To verify this statement, the device is place at three different spot on the back of the hand. Front spot, middle spot and end spot are selected to be tested (figure 11). The measurement taken in testing are flexion, extension, supination, pronation, radial deviation and ulnar deviation.
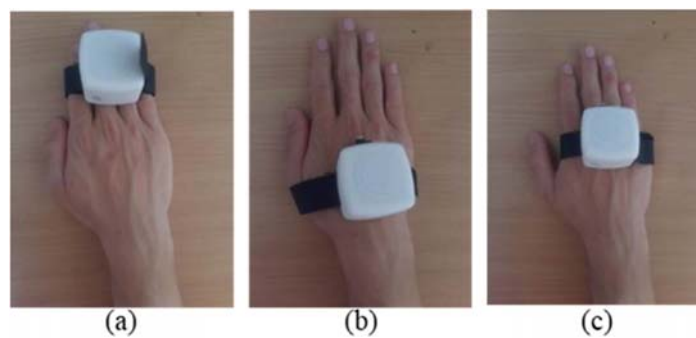

Figure 11. Location placement of the device. Front spot (a), middle spot (b) and end spot (c).

The data for the different location of placement are tabulated in table 4. For extension measurement, the data for middle spot and end spot are acceptable in around error difference of 1^0 to 2^0. For flexion measurement, middle spot data are higher by around 3^0 while for front spot and end spot showing unacceptable data. For supination measurement, all the data are unacceptable for the three location of placement. However, middle spot and end spot shows lower data compared to front spot. In pronation, three of the location placement show not much significant difference. But the end spot show slightly lower value compare to the other two locations. For radial deviation measurement, again front spot data

are not acceptable as the tolerance is too high. Middle spot and end spot data are much closer to the manual goniometer. But the end spot shows closer to the manual goniometer. Front spot also show unacceptable data for ulnar deviation measurement. Middle spot and end spot again show closer data to the manual goniometer. Middle spot show a higher degree of 3.14^0 while show 0.65^0 slightly lower than the goniometer. This shows the placement of the device should be at middle spot for extension and flexion. Supination and pronation can be either middle spot or end spot. Radial deviation and ulnar deviation is best to be placed at end spot. However, the end spot placement restricts the movement of the wrist.

Table 4. Comparison between manual goniometer and wrist measurement device for radial deviation and ulnar deviation.

Measurement	Manual goniometer	Wrist measurement device		
		Front spot	Middle spot	End spot
Extension	$40^0 – 50^0$	59.52^0	51.83^0	48.86^0
Flexion	35^0	48.51^0	38.54^0	50.58^0
Pronation	$45^0 – 50^0$	51.45^0	44.24^0	41.05^0
Supination	$50^0 – 55^0$	76.38^0	68.44^0	63.58^0
Radial deviation	10^0	18.63^0	12.48^0	11.00^0
Ulnar deviation	$15^0 – 30^0$	40.43^0	33.14^0	29.35^0

5. Conclusions and recommendations

The purpose of this study is to validate the reliability of the DMP generated sensor fusion data in measuring wrist range of motion. The DMP sensor used in this study is the MPU 6050 which consists of gyroscope sensor and accelerometer sensor. Each has own advantages and disadvantages. However, when both the sensors in use together, errors that possessed in the sensors can be corrected each other. A compact and small size case was developed to assemble all the components of the device. This device successfully obtained quite reasonable and acceptable data of wrist range of motion. With the algorithm that written using Arduino programming, the accuracy of the device able to give error in the range of 1^0 – 5^0. However, in some axis of rotation, the data is not stable and consistent. The data may drop in certain timing even though the position is holding still. There are some sudden high values that present during assessment of wrist range of motion. An android application which allows user to manual adjust the offset when there is sudden high value. However, in some certain case, the sudden value jump to more than one hundred which is not possible for user to decrease all the way to zero. There is still inconsistent and unstable data possess in this device. Placement of the device on the back of hand has a little effect on the data as well. Front spot, middle spot and end spot have been tested. Middle spot and end spot give a better and closer result to manual goniometer. End spot placement shows a good result on ulnar deviation and radial deviation. However, end spot placement restricts the movement of wrist. Middle spot placement so far give a decent result for all the assessment with some minor errors.

Testing are conducted with the present of physiotherapist from Pusat Kesihatan Pekan, Universiti Malaysia Pahang (UMP). Feedback from physiotherapist, the device is rather big in size. The testing for this device is only two subjects. The result might not be so accurate. In the future, we aim there will be more subjects to test this device. The movement of wrist is restricted due to the size. As suggested, a glove liked case might be better. The calibration on the device takes a long time to offset to zero. It could be further improved to reduce the calibration time. This could be done by writing new programming to reduce the calibration time. Sudden high value show the device is not stable which might affect the result. This might be the algorithm written is not working well in calibrating both the gyroscope sensor and accelerometer sensor. In future improvement, this could be done by improving the errors in the algorithm to compensate any errors that appears during assessment of wrist range of motion. MPU 6050 can work in a three dimensional model to further study the human motion. It can be done with the help of integrated software and camera to further assess wrist range of motion.

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