Design of angle measuring device for Synovial Joint Applications

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Abstract:

This study gives deep understanding about the design of synovial joints measurement device to measure the complete movement and range of motion of the joints in the body. Accurate measurement and analysis of joints and its range of motion (ROM) are important for assessing joint related health conditions and are valuable to clinicians for diagnostic and rehabilitation purposes. A physiotherapist may not predict the exact range of motion in joints for a patient because that isn't much easier to be done. But in this proposed work a solution is specified to develop a reasonably cheap and small size mobile measurement device utilizing the miniature sensor technology performing the task of capturing and detailing the range movements just as an optometric system. The proposed device accurately extract human joint orientation from the raw measurements of the sensor. This proposed device use the MPU6050 IMU unit to measure the rotational angle and range of motion in the joints where the data fusion between the accelerometer and gyro will be performed by the inboard MPU6050. Experiments were conducted to verify the reliability and feasibility of IMU sensor towards the design of this proposed measurement device. It's a development of an accelerometer based system to measure movement angle, velocity, acceleration and displacement of the joints. The application shows promising results of the usability of the IMU sensor in measuring the angles in all type of synovial joints. In this paper the neck angle, wrist angle and ankle angle are measured and compared with the standard range of motion.

Keywords* : *flex sensor, IMU sensor, range of motion, synovial joints.

1. INTRODUCTION

In India the most recurring joint illness is the Osteoarthritis (OA) is the mainly frequent problem of rheumatology, which prevails from 22% to 39%. The osteoarthritis is higher in women than in men and its occurrence increases, as they grow old. About 45% of women greater than the age of 65 have indications of this illness. It is found in 70% of the people above 70 years suffer from OA. This causes restricted mobility, among females in particular [2, p.518]. In India, the problem of replacement of joints is anticipated to rise remarkably at about 25-30 percent in the years to come, due to an increase in age related population and their inactive lifestyle. In recent times the entire joint alternative in India are calculated approximately to be more or less 40,000 - 50,000. When the biomechanical function of our citizens are assessed clinically and for research the knee angles are the most commonly reported problems. In [3, p.4 6, p.833, 12] it is reported that the people who are suffering with osteoarthritis, stroke and Parkinson's disease has abnormal joint flexion and extension patterns.

It is important to be aware of the functional and structural characteristics of the joints for osteoarthritis diagnosis and management [17, p.67]. OA targets the joints that are accountable for weight / load bearings such as hip, hand, knee, and ankle joints. Occurrence of OA in a particular joint is very much associated to their arrangement and efficient characteristics i.e., their structure and function. The knee and hip joints are considered geometrically i.e., cylindrical surfaces separate the knee joints and spherical surfaces divides the hip joints. The variation of the radii of these surfaces is from 2 cm to 100 cm. The variation of the sliding speed is from 0 cm/sec to 10 cm/sec. The hip joint area is larger to support the weight for the joint of the knee. The knee joint structure is that it can carry a weight four times the weight of the body. When the surface of the cartilage present in the joints are cracked or uneven, then the fluid in the synovial joints lose its non Newtonian character [10]

The 80 % of the post surgical patients after replacement suffer from post-operative muscle stiffness. They are able to walk, but 18% slower than their normal pace, climb stairs but 51% slower than their normal steps and have deficiency of quadriceps of almost 40% while compared to their other parts of the body. Measurement of kinematic variables is essential for carrying out an inverse dynamic analysis of joint movements. One of these variables is the joint angle, and its assessment is useful for assessing the effectiveness of severe work and to classify movement’s stressful conditions [7, p.389]. The development of joints is fundamental of each individual movement and complex in which many movement exercises are incorporated. And it is a precise assessment of human activity subjected to advanced methodology and information in the region of bio mechanics.

A solution for clinical applications and in-home treatment is the enhancement of low cost and simple inexpensive instruments. [15]. The joint angles can be measured using two methods: optical methods and universal goniometers. The digital goniometers’ uses are in orthopaedics, treatment, and restoration. The usage of Inertial Measurement Unit (IMU) sensors has its advantages of low cost, simple and robust design and is mostly used for motion tracking applications for rehabilitation in the orthopaedics. The wearable IMU sensors are a combination of gyroscope, accelerometer and magnetometer [8, 4]. In [1, p. 437], the author estimates the amount of functional information and the quality of motor movements using minimum measured input model structure protocol and sensors.

Likewise it enables medicinal staff to decide the foundation of movement deformity with reasons and effects. The focal portion of human movement is a consequence of the turning movement of specific joints. The correlative introduction of layers by and large communicates the edge of thought about fragments. In the human body, physical perspective is variation of rotating movement of a concerned joint which are changed into straight development in body. In the mean time in the human body, there’s a prompt redundant flexion and expansion of joints present, contrasted with an individual with a specific inability. The suitable approach of investigation can fill in an appropriate recovery Process in Patients within joints breakdown. There is working fields of frameworks for the detecting & assessment of joint properties and its distortion. In the early long stretches of present day micro electro mechanical based system, accelerometric gadgets are utilized to catch movements of the whole human body. Those gadgets are "mems" accelerometer. The application is a development examination of patient experiencing non-intrusive treatment. The universal goniometer is currently used to measure the joint angle which quantifies the Range of Motion (ROM). It has less accuracy with error ranging from 5 to 10 ° under repeated measures and the arms of the universal goniometer are not longer than 12 inches.

Hence, by using the normal conventional type goniometer a long subjective process time required and the accuracy will also be low. Thus, there exists a need to design a wearable digital goniometer for quick measurement of the angular motion with single hand allowing the physiotherapist to aid the patient with an easy measurement procedure. So, the new design of digital goniometer using MPU6050 would solve the therapist issue regarding the old type and it would also be accurate than the previous one and helps to measure the synovial joints very precisely. This MPU6050 will quantify the development investigation of the patients and that examination will assist the orthopaedics with predicting the careful scope of movement in joints which will be much helpful in patient's physiotherapy treatment.

In this research the objective is to develop wearable sensors for body joint angle measurement that can be potentially used to monitor patients activities while they stay at home using the flex-sensors attached to a wearable cloth, and inertial measurement units (IMUs) mounted on limb segments. The angle of the joints is measured by attaching a flex sensor between biceps and forearm of human arm. The output resistance of the flex sensor is mapped to its proportionate angle using microcontroller with simple algorithms and then the joint angle is measured by using IMUs. The measured angle is digitally displayed using LCD. The accuracy of each method is evaluated and compared. The user-friendly IMU sensor used in this research study gives correct measurement of the angle of joints. The flow diagram of the proposed study is given in figure 1.

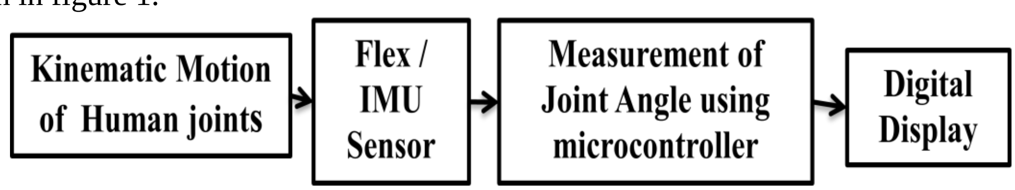

Fig.1. Flow diagram of the proposed study

2. METHODOLOGY

15 (men) and 5 (women) volunteers of the age group between 17 and 22 agreed to measure their joint angles of both of their upper limbs during April, 2019.

2.1 HARDWARE MODULE

2.1.1 FLEX SENSOR

It is a type of sensor which is flexible and used to measure the quantity of bending or change in deflection. The flex sensor employs a plastic strip over which there is carbon surface. When the strip is subjected to a deflection or a bend, the resistance will change. Change of resistance is directly proportional to the amount of bend. Hence it could be used as a standard goniometer. The sensor is coated with a polymer ink which is conductive. When the sensor is linear, a resistance of about 30Ω of resistance is given at the output. The resistance increases when the sensor is bent. Currently, 2.2 inches flex sensors and 4.5 inches flex sensors are being used in measurements. The working principle is the same but the size and its resistance values vary. So depending upon the requirement the size of the sensors is chosen. In this study a 2.2 inch flex sensor is used. These types of flex sensor are used for rehabilitation, servomotor control, computer interface, intensity control, music interface, or in applications where change the resistance of resistance occurs during bending. A picture of the flex sensor is given in figure 2.

Fig 2. Simple Flex Sensor Fig 3. Arduino UNO

The Aurdino Uno shown in figure 3 is an open source board which is incorporated with Atmega328p microcontroller. Here the digital and analog input / output (I/O) pins sets are equipped in the board for interfacing to other boards. The microcontroller program is written for interfacing the flex sensor and the LCD that is used for measurement and display of the joint angles

The angle of the elbow between biceps brachia and brachioradialis of human arm is measured using flex sensors. The change in resistance of the flex sensor is converted to a variable voltage by using voltage divider. The variable voltage is then interfaced to the ADC of the Arduino board. The digital voltage is mapped to the Range of Motion (ROM). The angle in degrees can be displayed using LCD display for easy visualization is shown in figure 4.

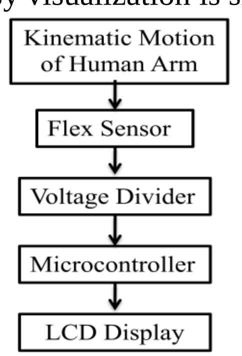

Fig 4 Methodology using Flex sensor

2.1.2 MPU 6050

The MPU6050 is a Smaller scale Electro-Mechanical Frameworks that comprises of a 3-pivot (Accelerometer) and 3-hub (Spinner) inside it. This quantifies the increasing speed, introduction, relocation and numerous other movement related parameters of the framework or article. This module likewise has a (DMP) Advanced Movement Processor inside it which is sufficiently amazing to perform complex figuring and subsequently free up the work for Microcontroller. MPU6050 sensor module is finished 6-pivot Movement GPS beacon. It joins 3-hub Gyrator, 3-pivot Accelerometer, and Computerized Movement Processor all in a little bundle. It has a Helper I2C transport to speak with other sensor gadgets like 3-pivot Magnetometer, Weight sensor, and so forth. In the event that 3-pivot Magnetometer is associated with the assistant I2C transport, then MPU6050 can give total 9-hub Movement Combination yield.

Figure 5. MPU 6050 IMU Sensor

2.1.3 MEASUREMENT OF JOINT ANGLE

Presently we have chosen, Full-scale Accelerometer scope of +/ - 2g with Affectability Scale Factor of 16,384 LSB(Count)/g and Gyrator full-scale scope of +/ - 250 °/s with Affectability Scale Factor of 131 LSB (Tally)/°/s.

Subsequently, to obtain crude information of the sensor, we have initially played out 2's supplement on sensor information of Accelerometer and whirligig. In the wake of getting crude sensor information, we can ascertain speeding up and precise speed by isolating sensor crude information with their affectability scale factor as pursues,

Accelerometer esteems in (g power)

Quickening along X-hub = (Accelerometer X hub crude information/16384) g.

Quickening alongside Y-hub = (Accelerometer Y pivot crude information/16384) g.

Quickening along Z hub = (Accelerometer Z hub crude information/16384) g.

Whirligig esteems in °/s (degree every second)

angular speed along X-pivot = (Gyrator X hub crude information/131) °/s.

angular speed along Y pivot = (Gyrator Y hub crude information/131) °/s.

angular speed along Z-pivot = (Gyrator Z hub crude information/131) °/s.

Temperature esteem in °/c (degree per Celsius)

Temperature in ° C = ((temperature sensor information)/340 + 36.53) °/c.

Assume, after 2' supplement we get accelerometer X tomahawks crude esteem = +15454

Then Hatchet = +15454/16384 = 0.94 g.

2.1.4 CIRCUIT DIAGRAM:

The circuit is designed, simulated and tested in circuito.io and then the circuit is soldered on a printed circuit board for measurement. The circuit board connection diagram is shown in figure 6

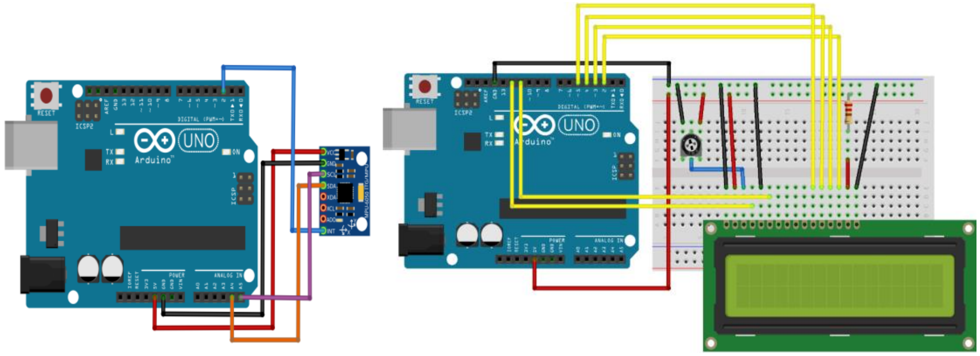

Fig.6. Circuit board connections

2.1.5 JOINT MOVEMENTS AND RANGE OF MOTION

The extension, flexion, abduction and adduction are the commonly recognized movements of the synovial joints. When the movement reduces the joint angle it is termed as flexion and when the joint angle inceses then it is called as extension. A joint in the body are created to allow movement in predestined directions. Although there are differences between people, the range of values tabulated in Table 1 is usually recognized in each individual joint as measured in degrees for a standard ROM. The range of movement of an individual is evaluated and compared by the physiotherapists with the normal values [9,11,13-15].

Table 1, Accepted values for ROM

Synovial joint	Flexion	Extension
Hip	0 - 120 °	0 - 30 °
Knee	0 - 130 °	130 - 0 °
Metatarsophalangeal Joint of Foot	0 - 30 °	0 - 80 °
Interphalangeal Joint of Toe	0 - 50 °	50 - 0 °
Shoulder	0 - 180 °	0 - 60 °
Elbow	0 - 150 °	150 - 0 °
Wrist	0 - 90 °	0 - 70 °
Interphalangeal Proximal (PIP) Joint of Finger	0 - 100 °	100 - 0 °
Interphalangeal Distal (DIP) Joint of Finger	0 - 90 °	90 - 0 °

3. RESULTS AND DISCUSSIONS

For this study, 15 (men) and 5 (women) volunteers of the age group between 17 and 25 in our institution were monitored for their joint angles of their upper limbs. As it is a non-invasive method, the procedure was explained and the flex sensor was placed as shown in figure 8.

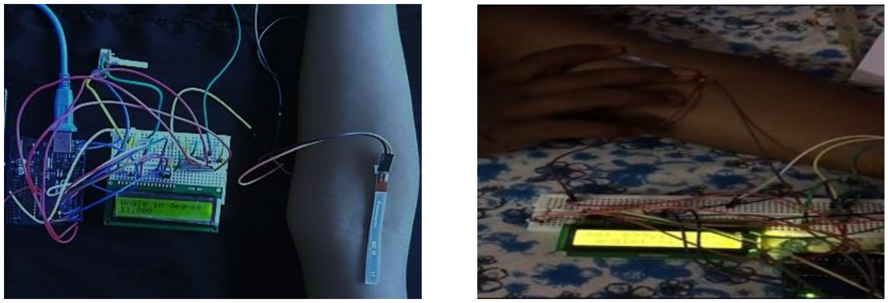

Fig 8. Measurement of joint angle using Flex sensors

The joint angles for various volunteers are measured and tabulated for extension of their elbows using flex sensor and IMU sensor as shown in table 2. In the table 2, W denotes women volunteers. Next the IMU sensors were used on the same volunteers for monitoring the joint angle. The output is tabulated in table 2. The normal range of flexion and elbow extension is 150 °. This is measured at 0 ° when the forearm is supinated and fully extended to 150 ° when fully flexed. Figure.9 shows the prototype for measurement of joint angles using IMU sensors.

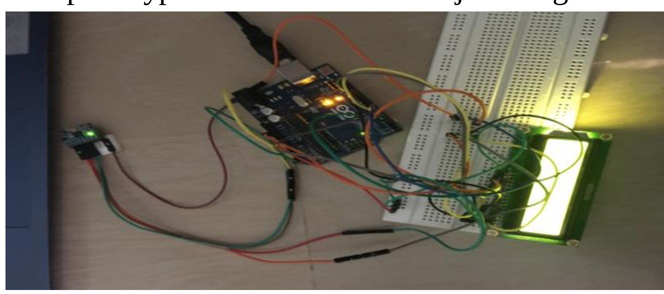

Fig.9 Prototype of the IMU design for synovial joint measurement

The IMU was also tested at the Danish Physiotherapy centre, Selaiyur, Chennai, India, for patients for different synovial joint problems namely neck, wrist and ankle. The results of the measurements are shown in figures 10 - 11. In figure 10 the output result observed from the code written for the display of measurement angle is shown. The placement of sensors for measuring the synovial joint angles is shown in figure 11.

Table 2 shows the data obtained for extension of elbow of the volunteers

Subject No.	Digital Goniometer output (°)	IMU sensor output (°)	Subject No.	Digital Goniometer output (°)	IMU sensor output (°)
Subject 1	117	118	**Subject 11(W)**	105	108
Subject 2	91	90	**Subject 12**	90	90
Subject 3	100	104	**Subject 13**	116	117
Subject 4 (W)	85	87	**Subject 14**	88	90
Subject 5	91	90	**Subject 15**	90.5	90
Subject 6	98	95	**Subject 16 (W)**	90	90
Subject 7	100	101	**Subject 17**	108	110
Subject 8	99	100	**Subject 18**	104	108
Subject 9	102	99	**Subject 19**	114	115
Subject 10	89	90	**Subject 20 (W)**	90	90

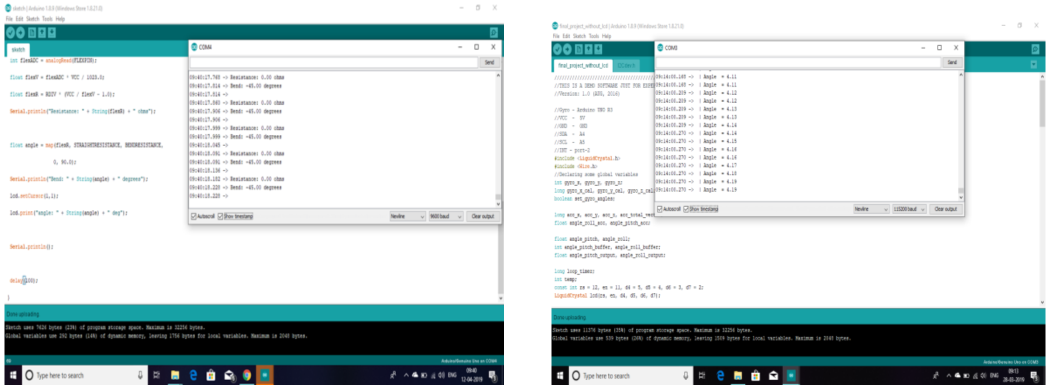

Figure 10 shows the flex and IMU sensor output for the joint angle measurement.

Figure 11 shows the IMU sensor tested on to the synovial joints for angle measurement.

In figure 11, the IMU sensor is tested on subjects with neck problems, wrist pain and ankle problems respectively. The observed output for joints are tested on subjects who came for exercises at Danish Physiotherapy centre and are tabulated in **table 3,4 and 5.**

Table 3. IMU angle output for neck joint angle

Neck joint angle	Normal values	Normal values	Observed angle	Result
Subject 1	flexion	0 - 45°	44°	Normal
	Extension	0 - 45°	45°	Normal
Subject 2	flexion	0 - 45°	44°	Normal
	Extension	0 - 45°	42°	Normal
Subject 3	flexion	0 - 45°	46°	Normal
	Extension	0 - 45°	43°	Normal
Subject 4	flexion	0 - 45°	24°	Abnormal
	Extension	0 - 45°	21°	Abnormal
Subject 5	flexion	0 - 45°	27°	Abnormal
	Extension	0 - 45°	30°	Abnormal

From Table 3, the lower values of the observed neck angle shows the abnormalities of the neck which may be due to Muscle sprain or cervical spondylatis. The observed output is tabulated of the wrist joint angle is given in **table 4.**

Table 4. IMU angle output for wrist joint angle

Wrist joint angle	Normal values	Normal values	Observed angle	Result
Subject 1	flexion	70 - 90°	80°	Normal
	Extension	65 to 85 °	75°	Normal
Subject 2	flexion	70 - 90°	84°	Normal
	Extension	65 to 85 °	82°	Normal
Subject 3	flexion	70 - 90°	76°	Normal
	Extension	65 to 85 °	69°	Normal
Subject 4	flexion	70 - 90°	54°	Abnormal
	Extension	65 to 85 °	61°	Abnormal
Subject 5	flexion	70 - 90°	27°	Abnormal
	Extension	65 to 85 °	20°	Abnormal

From Table 4, the lower values of the wrist angle gives the abnormalities of the wrist angle which may be due to loss of grip strength , loss of wrist flexion and also continous usage of keyboard. When the device was used to measure the ankle joints, there were variations of the observed angle from the normal values for some cases. The results are shown in **table 5.**

Table 5. IMU angle output for ankle joint angle

Ankle joint angle	Normal values	Normal values	Observed angle
Subject 1	Plantar flexion	0 - 50°	44°
	Dorsiflexion	0 - 20°	27.5°
Subject 2	Plantar flexion	0 - 50°	48°
	Dorsiflexion	0 - 20°	25.6°
Subject 3	Plantar flexion	0 - 50°	46°
	Dorsiflexion	0 - 20°	21°
Subject 4	Plantar flexion	0 - 50°	44°
	Dorsiflexion	0 - 20°	10°
Subject 5	Plantar flexion	0 - 50°	47°
	Dorsiflexion	0 - 20°	22°

From Table 5, it is observed that when the ankle is stressed more variation exists in the measurement of the angle. In addition, Croy et al. accounted that inversion stress by the side of an ankle joint plantar flexion of 30° was related with notably high extent alteration [14, 16]. Plantar flexion might be simply and more recurrently damaged with ankle sprains.

From the results we can see that the measurement of the synovial joints can be improved using flex sensor and IMU sensor. The program to achieve the angle is very simple using Aurdino UNO. The results show that the final output of the IMU sensor when measured for the patients are as follows

- The IMU sensor is easy to use and precise.
- The patients were comfortable when the sensor was placed on to them for measurement

- The accurate digital values were obtained which were in the range specified for the range of motion
- Easy to maintain
- Time taken for measurement and diagnosis is less

4. CONCLUSION

In this research study the flex sensors and the IMU sensors were designed using aurdino Uno for measuring the synovial joint angles. The sensors were tested on 20 volunteers. The proposed IMU sensor was tested in the Danish Physiotherapy centre, Chennai, for three types of synovial joint problems. For synovial joint measurement, the MPU6050 sensor works very precisely. The values of pitch and roll are converted into angle which helps better for understanding purposes. The final outputs value tested for patients are in degrees and accurate as expected. MPU6050 was very compact to use as compared to the goniometer scale which are very big in size and different size of scale required for different joints. The goniometer using flex sensor may also break in about 120 °. But MPU6050 can measure up to 180 ° stretch and it is much durable and it will not rupture like flex sensor. This MPU6050 helps in designing better artificial bone structure and material. This sensor has a potential to help the physical therapist for prescription of exercises depending upon flexion and extension of joint angles obtained. In future, early detection of the joint disorder can be done with the help of IMU sensors and the lubrication theory signals and some signal processing techniques can be used for analysis.

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