CONCEPTION OF A PORTABLE MEASUREMENT DEVICE FOR UPPER LIMB SPASTICITY

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ABSTRACT: *The aim of this work is to evaluate the sensor used in portable device measurement to measure upper limb spasticity based on Modified Ashworth Scale (MAS) level. A new instrumented measurement device is developed to assist physicians in quick decision-making. To improve this measurement, an angle sensor and force sensor were used to measure Range of Motion (ROM) and catch resistance of spasticity. Evaluation testing for angle sensor was done by comparison between the output value of the sensor and the actual angle from a manual goniometer. For the force sensor, evaluation was performed by comparison between experimental and theoretical values of the Force-resistance Curve provided by the manufacturer. The result from integration testing shows that the normal subject achieved no catch at Full Range of Motion (FROM). This shows that integration of force and angle sensor used are suitable for further use to quantify upper limb spasticity.*

Keywords: spasticity, Modified Ashworth Scale, rehabilitation

1. INTRODUCTION

Spasticity is a common complication occurring in the stroke population. Spasticity is a disabling condition that may hinder a patient's recovery. It was reported that 90% of spasticity, 36% of joint contractures, and 57% of tendon-muscle contractures (internal spasticity) were formed six months after stroke onset. The incidence of the first notable clinical manifestation of spasticity is 77.3% occurring during the first 2–3 weeks after stroke onset [1]. Spasticity is defined as a velocity-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex or clasp-knife phenomenon [2].

Spasticity can be demonstrated by performing neurological and musculoskeletal examinations on the affected limbs. It was divided into two types: (i) clinical method and (ii) biomechanical method [3]. Usually, clinical therapies refer to clinical methods such as Fugl-Meyer Assessment (FMA), Tardieu Scale (TS), Modified Tardieu Scale (MTS), Ashworth Scale (AS), and Modified Ashworth Scale (MAS) [4]. These scales measure muscle contraction strength and volume of voluntary movements (Medical Research Council Scale (Oxford Scale), MRCS) allows to estimate the strength of muscle. Several scales were usually utilized for the spasticity examination i) Modified Ashworth Scale ii) Tardieu Scale [1]. A biomechanical device is seldom used as an assistive device to measure spasticity. Examples of such devices include pendulum test, force or torque measurement, micrometers, and electromyogram (EMG) measures [4].

The rating scale is a conventional method to assess spasticity by classifying the level of spasticity severity by determining the resistance to passive range of motion. It is simple to use, however requires sound experience to have an accurate assessment. However, validation studies have reported a 'moderate' to 'good' intra-rater reliability and 'poor' to 'moderate' inter-rater reliability, dependant on the level of experience of the clinical assessors [4, 5]. Resistance produced by the spastic muscle sometimes may not be detected and can be missed in an inexperienced assessor due to the lack of automated measurement tools involve, hence, it may lead to parallax error [6]. Recognizing this shortfall, there is a need for an objective automated device to increase the accuracy of spasticity assessment that provides a reliable quantitative measure with a low interrater variability [3].

In this study, clinical data collection is proposed using MAS assessment to acquire spasticity data. Catch' or 'resistance', as stated in the MAS assessment descriptions, can be represented with sudden increment in a moment [Nm] and ROM can be represented as angle [Degree]. The angle where the first resistance occurs (catch) is an important feature to classify the severity level [7]. Several studies have utilized MAS as a standardized and validated instrument to evaluate their device reliability [8-13]. For the interest of this study, we measure specifically the spasticity of the elbow flexors. To elicit the spasticity, the elbow joint was brought into extension position by passive stretching along with the elbow range of motion (ROM). Different velocities were applied to be able to elicit spasticity by activating the stretch reflex; slow and fast stretch [14].

2. PRINCIPLE SOLUTION

Continuous model-based systems engineering is the basis of the first analysis to create a system design [15]. The principle solution of advanced mechatronic systems used is a specification technique called "CONceptual design Specification technique for the ENgineering of complex Systems" abbreviated as CONSENS®. The specification technique CONSENS is structured into several aspects; environment, application scenarios, requirements, function, active structure, behavior, a system of objectives, and shape [16, 17]. In this paper, function and active structure are used to visualize the detail of the overall system of the measurement device.

2.1 Function

Figure 1.0 shows the functions of the upper limb spasticity measurement device. Main functions are segregated into three functions cut-out; to be able to measure upper limb spasticity based on different severities of MAS, ability to emulate physician decision-making, and to avoid raters' variability. To measure spasticity stiffness, the device must be able to detect ROM angle and catch resistance. Additionally, the device needs to be able to emulate physician decision-making for quick clinical evaluation based on results displayed as well as to avoid variability among raters. The measurement device shall have consistency in the evaluation.

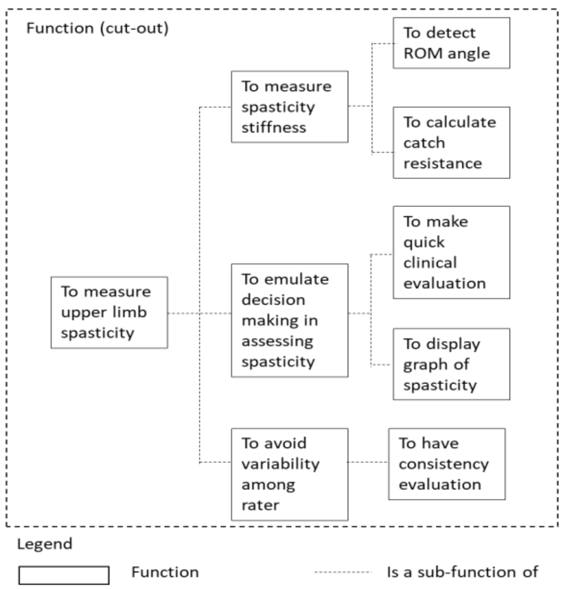


Figure 1.0 Function of Upper Limb Spasticity Measurement Device

2.2 Active Structure

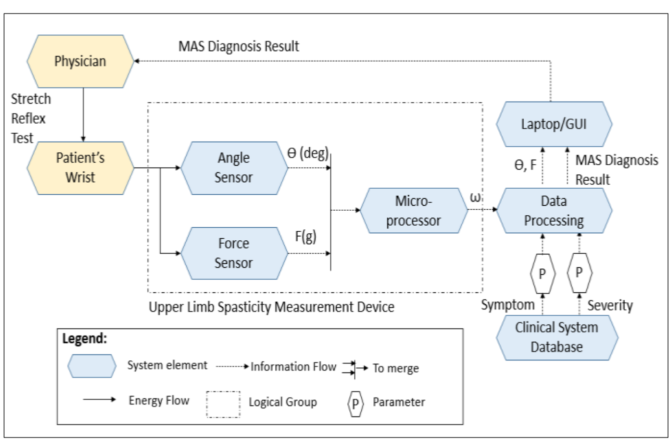


Figure 2.0 Active structure of Upper Limb Spasticity Measurement Device

Information flows are described in the active structure illustrated in Figure 2.0. Prior to the physician or therapist stretching the patient's forearm, the Angle sensor will detect the forearm angle input and the force sensor will detect force resistance through a microprocessor board; an open-sourced computer platform. Integration of both displayed in GUI for data recording. Then data is processed using machine learning model classification and the diagnosis result is displayed on GUI.

3. METHODOLOGY

3.1 Device Design

The measurement device was developed with a single degree of freedom (SDOF) with two main sensors; Accelerometer and a Gyroscope sensor ((MPU6050 from InvenSense Inc.)) and a Force Sensitive Resistor Sensor (FSR402 from Interlink Electronics, Inc.). These sensors attach to the wrist hand using Velcro tape and can be used on both hands (refer to Figure 3.0). In this measurement device, the Arduino UNO R3 microcontroller was used as a microcontroller that controls all sensors attached.

Figure 3.0 Placement of measurement device prototype

3.2 MPU6050 Sensor

MPU6050 sensor was used to measure the Angle Range of Motion (ROM) and angular velocity at the elbow joint of the spasticity patient. MPU6050 sensor has a six-axis of motion tracking device that consists of a three-axis accelerometer and three-axis gyroscope in a single chip that will help to measure velocity, orientation, acceleration, and displacement. Before this sensor can be used further, the sensor needs to calibrate first. In this paper, an experiment has been done with the MPU6050 sensor to evaluate the reliability of the sensor. The testing was conducted by comparing the output value sensor with the actual angle from the manual goniometer. The overall setup for this testing is shown in Figure 4.0. The MPU6050 sensor is a position parallel with the manual goniometer. The function of the jig indicator is to hold the protractor to stay fix. The additional arts used are button and color led to provide a more user-friendly interface during testing. The button function is to initiate the reading process of the sensor meanwhile the colored LED function is to indicate whether the reading process of the sensor starts. During testing, the output reading of the sensor was taken. It was started after a rotational movement of the sensor at different degrees of angle; 30º, 60º, 90º, and 120º. The process was repeated three times to evaluate the consistency of the sensor. The data was recorded and plotted into a line graph.

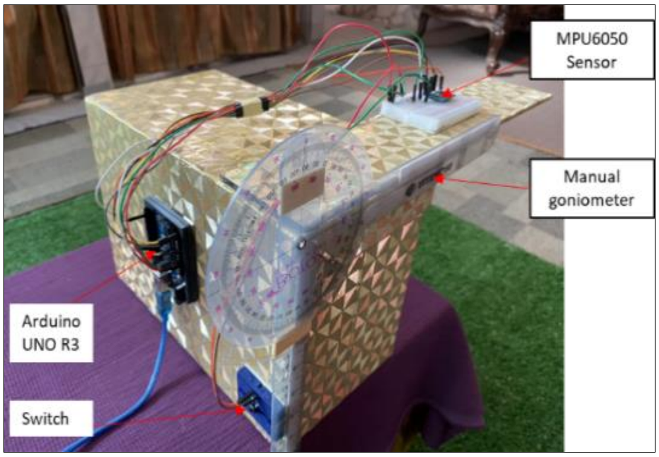


Figure 4.0 Setup for MP6050 sensor testing

3.3 FSR402 Sensor

Force Sensitive Resistor (FSR) is a function to detect any physical pressure, squeezing, and weight. It is an electric sensor made up of thick polymer film that changes resistance or conductivity value when force or pressure is applied. In this study, the FSR402 sensor was used to measure force and catch resistance. Evaluation of the FSR402 sensor was performed by comparison between the experimental value and theoretical value of the resistance curve from Interlink Electronics FSR® Integration Guide. In this testing, three sets of procedures were conducted for different dead weights. The value of dead weights used is 85g, 137g, 164g, and 223g. During testing, a soft white face tissue was placed between the sensor and dead weights to absorb error and enhance the response (refer to Figure 5.0). The data were taken after showing a constant value at least 3 times in a row then measurement of force data can be recorded. The force-resistance curve method was used as the theoretical value to evaluate the relationship between the resistance and magnitude of applied force on the FSR402 sensor.

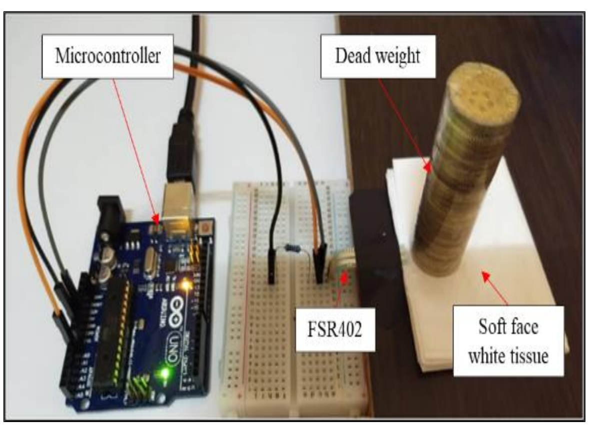


Figure 5.0 Setup for FSR402 sensor testing

3.4 Data Acquisition

A normal subject without spasticity was recruited to evaluate the integration of both sensors. Before the assessment began, the measurement device is attached to the patient's wrist. The procedures begin with slow motion through the range of movement. The physician stretched the forearm of the patient until reaching a fully stretched position during slow extension. The estimated time for reaching a fully stretched position was about 7 to 8 seconds and repeated three times. The clinical procedure continued with a fast motion session. The physician stretched the patient's arm as fast as the patient can obtain a catch position. The estimated time to complete the fast motion session was about 3 seconds and repeated three times. Both motion sessions were recorded and the evaluation of the level of spasticity was determined by the physician. Then, the data was analyzed and validated visually with MAS0 theoretical since the normal subject is similar to MAS0 [18]. Figure 6.0 illustrates the system overview of the device set-up connection for the data acquisition pilot prototype. In this paper, will be discussed for evaluation of the data acquisition part using measurement device prototype. For the data processing part and above process, a data science platform for smart diagnosis of upper limb spasticity has been developed and explained by others [19, 20].

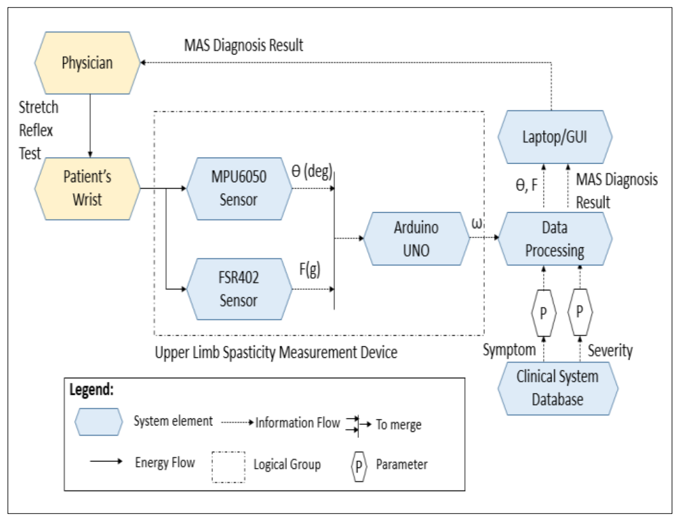


Figure 6.0 Device setup connection for the data acquisition pilot prototype.

4. RESULT AND DISCUSSION

Figure 7.0 shows the range value for the sensor evaluation at a certain angle, which is at 30°, 60°, 90°, and 120° (based on the actual angle from the manual goniometer). This test is to ensure that the MPU6050 sensor enables to read of the target angle accurately. Figure 7.0 shows that the MPU6050 sensor is able to generate almost a similar angle of manual goniometer by providing below 20% of percentage error of each trial. But the value of the percentage error is high since the MPU6050 sensor showing an inaccurate value. This error was occurred during handling the position of the MPU6050 sensor that affect the reading value.

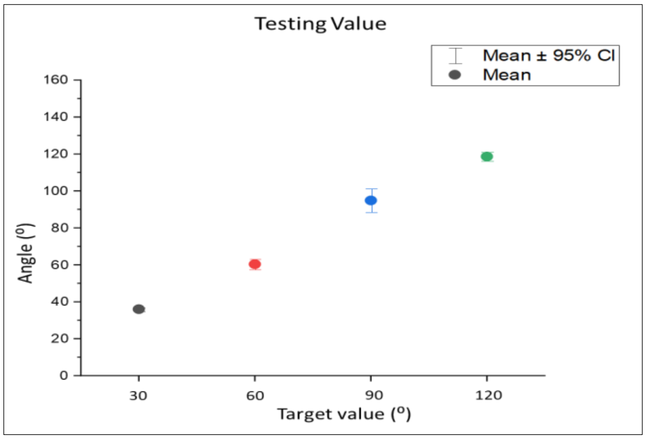


Figure 7.0 Results of evaluation MPU6050 sensor

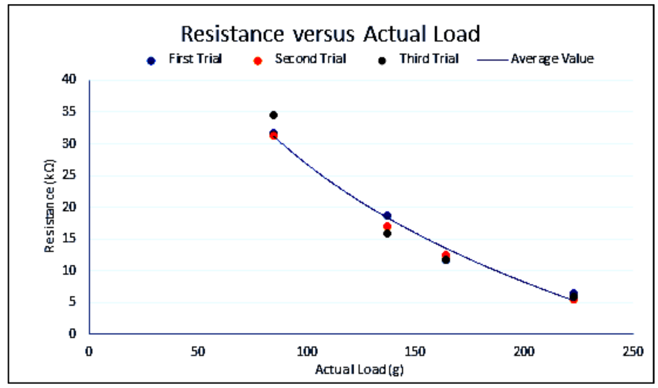
Figure 8.1 is the result of the force-resistance curve method. The load in this case refers to the force applied. The graph provides an overview of FSR402's typical response behavior. For this method, the value of FSR resistance is obtained through the formula below:

$$FSR = \frac{(Vcc-V)\times R}{V} \qquad (1)$$

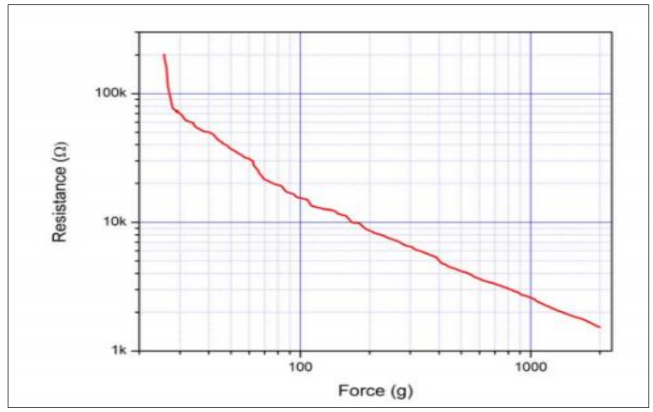
The resistive value of FSR is depending on how much the pressure. If no pressure is applied, the sensor acts as an infinite resistor (open circuit). The maximum resistance obtained when the load applied is 85g with 32.49kΩ and the minimum resistance obtained at load 223g with 5.95kΩ. The result, explains the higher pressure applied to the head of the sensor, the lower the resistance will be.

Furthermore, from Figure 8.1, the pattern of the curve clearly shows the relation between load and resistance is inversely proportional to each other. The pattern of the curve obtained from this experiment same as the curve provided by Interlink Electronics for the FSR402 model (refer to Figure 8.2). However, the value of the resistance at a particular applied force is not the same as provided value since the type of actuator used in this experiment is different from the stainless steel actuator used in the catalog. The braking force that swings the resistance from a higher to a lower value is determined by the substrate and overlay thickness and flexibility, size, and shape of the actuator. This result proves that the FSR402 sensor was reliable to use to measure the force given.

Lastly, the result of the integration test between both sensors has been shown in Figure 9.0. From the graph of slow extension, it can be observed that FROM of the subject is at 180°. Refer to the fast extension graph there is no resistance happen before full ROM at 180° prove that this is a normal subject without spasticity. Based on the MAS0 description, there is no muscle tone occur [21]. In addition, these results show that the developed measurement device was able to produce both values of force and angle simultaneously and can be used to quantify spasticity. It is necessary to extend the experiment with spasticity subjects to validate the device for future works.



(8.1)



(8.2)

Figure 8: (8.1) Result of evaluation FSR402 sensor. Figure (8.2) Curve provided by Interlink Electronics for FSR402 model

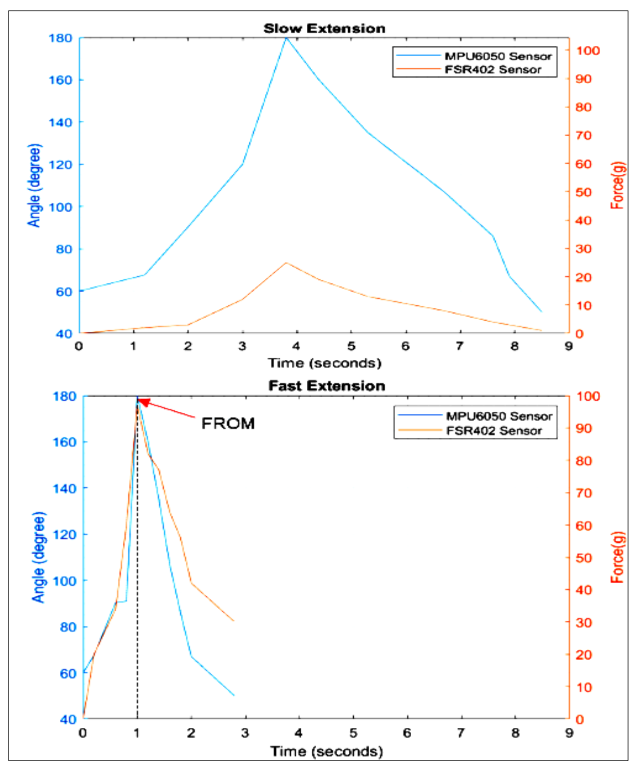


Figure 9.0 Results of integration test during a slow and fast assessment

5. CONCLUSION

This paper presented the evaluation test of the sensor used in measuring the device for upper limb spasticity and the preliminary test of device functional. This assisted device shows the more intuitive measure of upper limb spasticity using any force and angle sensor without the risk associated. Due to a limited number of subjects, this device needs future experiments to be conducted on a larger sample size to provide a reliable quantitative measure. Moreover, there is a lot of components in the device that need to be minimized by customized printed circuit board (PCB) and change for a better type of force sensor. In the future plan, the complete Upper Limb Measurement Device will be integrated with a data science platform for smart diagnosis that can emulate physician's decision-making in upper limb spasticity.

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