A FSR Sensor Cuff to Measure Muscle Activation During Strength and Gait Cycle for Lower Limb

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ABSTRACT

The assessment techniques used for people who experience muscular issues, regardless of the cause, are crucial to resolve the issue and fill the gap left by the deficiency in their muscles. The amputees’ demands in their rehabilitation process are made more evident by evaluating the residual limb muscles. The time-varying muscle activity of the amputees weakens the efficiency of using these fixed positions inside the socket, which leads to a great challenge for them to continue using the prosthesis in this case. Depending on the daily motion activity or routine of the amputees, a change in the level of muscle activation may occur because every motion activity has its dynamic that depends on muscle activity. For this purpose, a new reliable cuff system using a simple, non-invasive sensor based on a force-sensitive resistor (FSR) which can measure muscle contraction, is presented in this study. The cuff system was designed by Autodesk Inventor software and used Cura for slicing functions. This design was printed by Creator-Pro 3D printer as an FDM type. The cuff includes 8 FSR sensors printed with TPU and APL for the cube. Applying FSRs on the skin senses the mechanical force exerted by the underlying contracting muscles. Regarding FSR signals and data collection and display, Datastreamer by Microsoft Excel was used for this purpose. Five male non-amputee subjects were involved in this study to do two activities (strength muscles and gait cycle). Each activity was subjected to two tests, the first conducted above the knee, while test 2 was below the knee. Rectus femoris (RF) and tibialis anterior (TA) muscles were targeted as a positioning reference for above and below the knee tests, respectively. Through the experiments, there was no complaint from the subjects about the surface of the cuff touching the skin. Still, the issue revolved around the tightness of the cuff, especially at the above-knee level for both activities. As thigh circumference, the cuff stretching efficiency was achieved over maximum stretch capability at 63 cm. After more than 50 trials with the two activities mentioned above, there was no change in the cuff dimensions either for maximum or minimum size, i.e., without stretching occurring. F1 - all individuals for both activities displayed no appreciable signal variations and began with high levels of values, according to the signals data. That results from the tightness of the cuff on the limb. As a result of its site being unfavorable to any muscle activity, F2 presented poor signals in both activities for all participants. The cuff size needs to be reevaluated to prevent the problem of cuff tightness. The findings of the trials generally demonstrated the muscles’ active locations and the change of activity taking place in those positions. On the other hand, the findings of the experiments also presented the inactive positions.

INDEX TERMS

Force sensitive resistor, muscle testing, prosthesis control.

I. INTRODUCTION

Prostheses, especially powered ones, are the ideal solution to deal with the difficulties arising from amputations that lead
to significant mobility challenges. Amputee individuals face many daily difficulties and challenges in their usual activities such as walking, ascending, descending stairs, and other activities that they depend on daily [1], [2]. General statistic shows that there are ten million amputees in the world. The dominant type of amputation is the lower limbs, in which the most common one to be below the knee. In general, the forces, balance, and movement of amputees are changed due to permanent physiological change that happened to them [3]. It is also reported that the percentage of lower extremity amputations is 84 %, as a common amputation [4]. Some studies dealt with a significant problem that affects both the team that provides services to those who have had limbs amputated and the amputees themselves in how they react to the replacement limb. Even though some people who use artificial limbs accept it, others do not. Accepting the prosthetic limb may be challenging for a while due to several causes, such as pain relief, ease of use, and dealing with any changes on the residual limb [5].

Reaching the highest level of functioning of the remaining limbs compared with the normal level of movement is the main goal of rehabilitation. Although there is remarkable and strong progress and improvement in the performance of movement of amputees, there is still an urgent need for further development to achieve the main goal which is to enhance the movement performance and achieve the maximum extent of natural movement before amputation. Hence, based on that, there are many ongoing research and studies to achieve this goal [6].

For those who suffer from muscle problems for any reason, their evaluation methods play a significant role in solving the problem and filling the gap resulting from the defect in their muscles. Assessing the residual limb muscles clarifies the amputees’ needs in their rehabilitation journey. Manual muscle testing (MMT) is a prevalent method with a long history of measuring and evaluating muscle strength in clinical settings by measuring the muscles’ peak isometric force and tracking the improvements of the movement during the treatment period [7]. It is a standard procedure conducted by most health care disciplines, including rehabilitation, using a grade scale between 0±5: 0=no activity, 1=trace activity, 2=poor activity, 3=fair, 4=good, and 5=normal. The assessment of MMT does not take a long time, and it will not be stressful for the subjects, whether the amputees or the ones suffering from myositis as shown in Fig. 1 of reference [8]. However, the issue here is to repeat the evaluation process for the muscles to increase the reliability of the evaluation, and this takes time and effort from both parties, whether the amputees or the practitioners. The assessment process is applied to several groups of muscles, and each group has a specific assessment procedure. In addition, an important factor must be taken into account, which is the age discrepancy. According to the powered prosthesis, the time-varying muscle activity of the amputees weakens the efficiency of using these fixed positions inside the socket, which leads to a great challenge for them to continue using the prosthesis. That leads the practitioners to repeat the manual muscle test on the residual limb for the prosthesis user to check out the new muscle’s activation position. However, the quality and the sensitivity of detection of the mild weakness by MMT have decreased and exhibit ceiling effect [7], [9], [10], [11], [12], [13], [14].

Several other developed methods have been introduced in recent years for the detection of muscle activity [9]. Muscle activity system detection can be classified into two parts which are biomechanical system and bioelectrical system. Measuring muscle activation by the biomechanical system applies to various sensors, including an encoder, a load cell, and a torque sensor. These sensors could measure the observed positional values of the interactions between the prosthetic system and the users, torque, and the interaction force. However, they cannot be positioned within the design of the prosthesis, i.e., inside the socket as shown in Fig. 2 of reference [17].

In addition, biomechanical sensor systems have significantly enhanced the feedback in gait-assisting robots such as Lopes (lower extremity powered exoskeleton), and Alex (active leg exoskeleton) [9], [18], [19], [20], [21]. The issue of recognizing the intention of users of the prosthesis for movement by using a biomechanical system in rehabilitation systems takes significant concerns of importance [22], [23]. It gives the advantage of being effective in measuring muscle activation and control [24]. Accordingly, a strategy for controlling prosthetics using force sensing resistors (FSR) was proposed [25].

In contrast, measuring muscle activation by the bioelectrical system is vastly used in various methods applied to multiple sensors. However, these previously developed techniques encountered obstacles in assessing muscle activity: bioelectrical impedance analysis (BIA), electrical impedance myography (EIM), electrical impedance tomography (EIT), and surface electromyogram (sEMG) [9]. EIM and EIT are non-invasive techniques used to measure muscle activation. However, despite the many advantages of MIT, there are...
limitations in detecting muscle activity. As for the EIT technique, it has been widely applied in medical research [5], [9]. The BIA is also a non-invasive method used to estimate the user’s body composition, including their fat-free mass and the percentage of total water amount in the body by applying electrical currents through the body [26], [27], [28].

Electromyography (EMG) is employed to analyze various motion activities, including gait cycle, lifting loads, jogging, squatting, and other kinds of activities for the upper limb or the lower limb amputees which would enhance the rehabilitation processes for prosthesis users [29], [30], [31], [32], [33], [34]. EMG sensors are divided into two types: surface EMG (sEMG), and intramuscular EMG sensors (imEMG). The problems that EMG signals may face as a control element in the powered prosthetic limb are skin conditions such as sweating, burns, and others. However, the need to determine the appropriate location for the sensor is essential because the location of the EMG sensor should be exactly above the target muscle [35]. These factors greatly affect the performance of the algorithms used for myoelectric control [36]. Moreover, the sensitivity of signals to electromagnetic interference and other noise sources should be considered an issue [24]. The study of [37] showed that the volume of processes needed by EMG signals including low pass filtering and rectifying operations leads to a noticeable delay. This delay is greater than the delay counted in FSR signals called physiological electromechanical delay (EMD) between the muscle’s electrical activation and mechanical contraction. In addition, the FSR signal is unprocessed and can be utilized directly. However, it will not be appropriate when investigating the muscle activity in the residual limb because it may not cover all the muscles’ active positions.

The main goal of rehabilitation for amputees is to bridge the gap in their motor abilities. Powered prosthetic limbs are one of the ideal solutions to contribute to achieving this goal. Despite its many advantages, further contributions are needed to promote the notion of continuous muscle evaluation due to the continual change in its efficiency throughout time. Therefore, this study aims to design a new reliable FSR cuff system that can be used to test the muscles’ activities in lower limb (MMT).

II. METHODOLOGY

A. FSR CUFF SYSTEM DESIGN

1) CONSTRUCTION OF THE CUFF SYSTEM

As shown in Fig. 3, the methodology of the design is divided into three parts. The first part consists of two steps which are circuit design and the coding step using Arduino software. This is followed by the second part which includes the cuff design which was designed by Autodesk Inverter software, Cura software for the slicing process, and selecting materials to print the design with Creator-Pro printer from Flashforge. The last part is the assembly of components of the system as shown in Fig. 4. Table 1 provides an overview of the equipment used in this study.

![Flowchart](image1)

![Flowchart](image2)

FIGURE 3. Flowchart of the methodology of the design.

2) FSR SENSOR SYSTEM DESIGN

The human touch control pattern employs FSR sensors to facilitate the control of electronic devices, which have been done after improving the sensitivity of these sensors to the force. The structure of the cuff mainly consists of FSR sensor model from FSR 402, Interlink Electronics which is used for force measuring [38]. The proposed sensor model has satisfactory features and performance in force measuring [39]. Hence, the FSR 402 model has been selected because of
its appropriate fit with the design. In this study, eight FSR sensors are included in the cuff system design controlled by one Arduino-Nano, as shown in Fig. 5.

FSR sensor consists of four layers, as shown in Fig. 5(a) of reference [40], which are as follows: 1- The base is TPU material with a rear adhesive surface. This adhesive surface was tested on the surface of the LPA cube. However, it did not give the desired stability, so the double-sided thermal tape was used. 2- Resistive carbon elements. 3- conductive silver layer. 4- Cover film to protect the conductor where the diameter of the active area is 12.7 millimeter (mm) and with a thickness of 0.55 mm. In addition, it is fast and easy to integrate, and has four connection options such as solder tab that is selected in this research as it provides more confidence according to the cuff design, female contacts, female contacts with two-pin housing, and bare tail as shown in Fig. 5 (b) of reference [38].

FSR is a type of piezoresistive element. The resistance of the FSR can reach more than 10 megaohms (Mohm) when the pressure on the active area is zero, and this resistance decreases when a force is applied to it. equation (1) illustrates the classic circuit (voltage divider) used to capture the change in resistance, where the value of the reference resistance R(n=8) here is 100 Kohm. In this research solder tab was selected as it provides more confidence according to the cuff design. The output voltage is calculated by the following equation:

$$V_{out} = \frac{V_{cc} \times R}{(R + R_{fsr})} \quad (1)$$

3) THE CIRCUIT SYSTEM DESIGN
The Arduino-nano board serves as a 5V power source for the measurements and the sampling input [40]. The power source for the Arduino board is taken from the laptop’s USB port via a USB cable from Type B. To jump wires for connecting function, one end of the wire is attached to the 5V power supply pin by soldering. The other end of this wire is connected to several connectors housing to serve all the sensors with power. The same method is done with the ground line from the ground pin (GND). One end of the wire is connected to the several connectors housing. Eight standard resistors of 100 Kohm are applied to each sensor to capture

| TYPE      | ITEM                          | DESCRIPTION                                      |
|-----------|-------------------------------|--------------------------------------------------|
| Hardware  | FSR sensor                    | From (FSR 402, Interlink Electronics) QQ shop as supplier |
|           | Arduino-Nano                  | Male and female connectors wire                  |
|           | ATMEGA328                     | Female terminals connector                       |
|           | Jump wire                     | To fix the sensor on the PL A cube surface       |
|           | TPU 1.75mm                    | Solid                                           |
|           | PLA 1.75mm                    | Flexible and stretchable                        |
|           | Creator-Pro printer           | FDM printer from FlashForge                      |
|           | SD card                       | Memory card                                      |
|           | Laptop                        | To show the results and deal with the software programs used |
|           | Cable                         | USB Type-B                                       |

| Software  | Arduino Software (IDE)        | To deal with Arduino-Nano and coding part       |
|           | Autodesk Inventor View        | To design the cuff and the cube. It’s one of programs software that can use with Creator-Pro printer |
|           | Cura                          | Ultimaker company Slicing function               |
|           | Microsoft Excel Data streamer | To monitor data streams from Arduino             |
the change in resistance. One end of the resistance is branched into two-wire as a junction; one is connected to one of the electrodes of the sensor and the other with a GND pin. The other end of the resistor is connected to the Analog input pin for voltage reading which is applied to all eight sensors as shown in Fig. 6. Fig. 4 shows the connector housing that is placed inside the PLA cube.

4) THE ARDUINO CODING AND DATA COLLECTION
In this paper, the code script is not complicated. It is straightforward and includes several stages and conditions. Initially, each FSR sensor and its standard resistance of 100 Kohm is defined on its connection point with the analog pins from A0 until A7. It is considered as configuring the serial communication with the computer in the setup function of the code. Meanwhile, in the loop function, the analog reading data are taken from the FSR resistor divider and displayed on Datastreamer by Microsoft Excel. The output voltage will be zero if there is no pressure applied and 5 V if maximum pressure applied. Data Streamer will capture these data with a delay applied (17 ms), and the value will be between 0 - 1023 as an analog voltage, depending on the pressure applied [38], [40]. A conditional tool is used to set some conditions as follows according to the MMT grade scale: the max value for “no pressure applied” reading on the sensor is 5 (this will be equal to 0 and 1 in MMT grade scale), while the max values for “light pressure applied” and “medium pressure applied” are 100 (equal to 2 in MMT grade scale) and 200 (equal to 3 in MMT grade scale), respectively. However, “high pressure applied” will appear if the value exceeds 200 (equal to 4 and 5 in MMT grade scale). Fig. 7 provides a simplified software flowchart for the cuff system.

5) THE CUFF’S MATERIALS AND 3D PRINTING PROCESS
Several studies reported on TPU and PLA application in the 3D printing of prosthetics limb. In this study, these materials are selected because of their characteristics [41], [42]. Table 2 provides the features for each filament. The same sort of printer (Creator-Pro 3D printer) is chosen for this work as it can be utilized with these materials. This 2016 model printer from FlashForge is an FDM 3D printer. It is based on an open-source technology principle that provides high-quality printing, contributing to development and modification flexibility. Because the printer uses open-source technology, it is compatible with many design programs and not limited to a specific program [43]. In this research, Autodesk Inventor is used to design the cuff system. It has a design plate made of high-efficiency aerospace-grade aluminum with a thickness of 6.5 mm. Even with constant exposure to heat, the board always remains flat and does not undergo any changes as shown in Fig. 8. It can also print dual-color and dual filament at the same time. Table 3 provides feature summary for this printer.

Autodesk Inventor is an engineering software developed by Autodesk Corporation. It creates 2D and 3D models and has a powerful combination of parametric, live, and freeform design capabilities that provides high quality model design [44]. As mentioned earlier, this program is compatible with the Creator-Pro printer. The design is transferred to the
printer in STL file format by SD memory card. Since the study relates to the lower extremity of the body, the average circumference of the thigh and leg is determined to build the dimensions of the cuff. Based on reports from the Centers for Disease Control and Prevention (CDC), the average thigh circumference for males and females is 21 inches. In contrast, the average leg circumference for males and females is 23, which equals to 53.34 cm and 58.42 cm, respectively [45]. The average thigh circumference is determined as the maximum stretch capability the cuff could reach, where this value is rounded up to 60 cm. As for the minimum value which is considered the circumference in the natural size of the cuff without any stretching, it has been set at 30 cm to maintain the cuff’s appropriate thickness that matches the stretching’s maximum value. Any value higher than this will make the cuff wall to be very thick, and if it is less than this value, for example, at 25 cm, the cuff wall will be of a light thickness that may lead to damage when conducting experiments on the thigh muscles. As shown in Fig. 9, the dimensions are calculated by the following equations:

\[ r = \frac{C}{2\pi} \]  
\[ d = 2r \]

FIGURE 8. Creator-Pro 3D printer.

Cura 3D is one of the best software used for slicing functionality. It is an open-source program from Ultimaker that does not require any subscription. It helps determine the print quality of the model to be printed on any 3D printer. As shown in Fig. 10, the cuff design is divided into two parts because another part (PLA cubes) will be integrated with it. Moreover, the printer cannot print all the design units simultaneously, as they are printed one by one and combined with glue at the end. Cura can also calculate the time required to print, the weight, and the amount of material used. Regarding the cuff, it took 14 hours and 16 minutes to print the entire cuff design, and it consumed 13.75 m of TPU at the weight of 80 g. However, the PLA cube took about an hour to print, weighed only 6 g and consumed 2.18 m of PLA for each cube.

### TABLE 2. Features of TPU and PLA filaments.

| FEATURES                  | PLA | TPU |
|---------------------------|-----|-----|
| Flexibility               | Bad (solid) | Perfect |
| Printing temperature      | 180 - 230 °C | 190 – 245 °C |
| Heat Resistance           | Bad | Good |
| Biodegradable             | Partly | No |
| Recyclable                | Yes | Yes |
| Supplier in Malaysia      | Available | Available |

### TABLE 3. Feature summary table for Creator-Pro.

| FEATURES                     | CREATORE-PRO                |
|------------------------------|------------------------------|
| Nozzle Diameter              | 0.4mm                        |
| Print Speed                  | 30 – 100 mm/s               |
| Maximum platform Temperature | 120 °C                      |
| Filament                     | PLA, TPU, ABS, PETG, RESIN, etc. |
| Filament Diameter            | 1.75 mm                     |
| Absorption of Moisture       | Yes                         |
| Strength                     | Medium                      |
| Water resistance             | Medium                      |
| Heat Resistance              | Bad                         |
| Biodegradable                | Partly                      |
| Recyclable                   | Yes                         |
| Supplier in Malaysia         | Available                    |
| File Input Format            | 3MF, STL, OBJ, FPP, BMP, PNG, JPG, JPEG files |
| Software                     | Flash Print, Simplify3D, Cura, Autodesk Inventor and more |

### B. EXPERIMENTS

In this study, the signals are recorded by eight FSR sensors controlled by one Nano-Arduino. Experiments included two types of activity: 1- Strength muscles, and 2- Gait (normal walking) with an unspecified speed. In contrast, in a different research by Silverman et al. (2008), participants walked at four randomly chosen speeds, ranging from 0.6, 0.9, 1.2, and 1.5 m/s, over a ten-meter straight track [46]. These activities are selected because they include the most important activities in daily life that are of particular interest to the TTamp. Two tests are performed for each activity, test 1 (above the knee), in which rectus femoris (RF) is a targeted muscle as a positional reference. Meanwhile, test 2 (below the knee) uses tibialis anterior (TA) as a targeted muscle and a positional reference for this level. Five non-amputee subjects are also included in current study, while just one individual was used in the study of Razak et al. [47]. As indicated in Table 4, these participants have variety of measures, including age, height, weight, body mass index.
FIGURE 9. Cuff design.

FIGURE 10. Slicing process by Cura.

BMI data have been categorized following the World Health Organization (WHO) [48], and other measurements. The BMI is computed by dividing the weight in kilograms by the square of the height (kg/m²). With the knowledge that the normal range is between 18.50 and 24.99 (kg/m²), the goal of BMI assessment is to diagnose obesity and determine whether the individuals are in the normal range or not to ensure that there is no adverse impact on movement or the measurements of the FSR signals. High BMI raises several health concerns [48], [49], [50], [51], [52]. Before starting data recording, the subjects are asked to perform some simple exercises which are tension of the leg muscles, flexion and extension of the knee joint and jumps within five minutes to stimulate the muscles and ensure satisfactory performance of the FSR signals. The subjects completed five successful trials for each activity, to which the average of these trials is adopted. F1 is located on the rectus femoris (RF) muscle as all subjects’ above knee reference position. In contrast, it is located below the knee on all subjects’ tibial anterior (TR) muscle as a reference position.

TABLE 4. Non-amputees subject’s measurements.

| Participants | S1 | S2 | S3 | S4 | S5 |
|--------------|----|----|----|----|----|
| AGE (Y)      | 25 | 33 | 24 | 23 | 28 |
| Weight (KG)  | 68 | 90 | 72 | 84 | 65 |
| Height (M)   | 1.65 | 1.81 | 1.65 | 1.77 | 1.7 |
| BMI (KG/M²)  | 24.97 | 27.47 | 26.44 | 26.81 | 22.49 |
| States       | N  | OW | OW | OW | N  |
| CAK          | 38 | 43 | 49 | 46 | 39 |
| CBK          | 50 | 52 | 37 | 44 | 42 |
| LK WIDTH (CM)| 10.5 | 10.8 | 11 | 10.1 | 11.6 |
| LT LEFT (CM) | 41 | 41 | 42 | 42 | 44 |
| LF LEFT (CM) | 46 | 45 | 45 | 45 | 41 |

Note: N= Normal, BMI = Body Mass Index, S= Non-amputee subject. O= Obesity, OW= Overweight, M= Male, F= Female. N/A= Not available. C = Circumference. LK= Lift knee. LT= Length of tibial. LF= Length of femoral.

III. RESULTS AND DISCUSSION

In this paper, in terms of the cuff, the complete design was printed in 14 hours and 16 minutes, using 13.75 m of TPU filament weighing 80 g. The PLA cube, on the other hand, took a little over an hour to produce, weighing just 6 g, and used 2.18 m of PLA filament for each cube. It took almost nine hours to print the eight cubes, with total weight of 48 g and used 16.64 m of PLA filament. The total weight of the cuff system is 128 g, excluding electronic parts, for 23 hours and 16 minutes of printing prude. The cuff printed with a minimal cost and low-entry in proficiency of use that can be useful in developing countries. The cuff as well designed with condition to be used for clinical practitioner. The smoothness of the surface of the cuff, which in turn will be in direct contact with the subjects’ skin is carefully considered to avoid any obstacles that may occur during experiments, such as scratches on the skin’s surface which will negatively affect the performance of the cuff users’ activities. Average thigh circumference (maximum stretch capability the cuff could reach and minimum size, i.e., without stretching occurring) is 60 cm and 30 cm, respectively. In the experimental part, after more than 50 trials with the two activities mentioned before, there are no changes done in the cuff dimensions either for maximum or minimum size. Further to that, the cuff is also tested with stretching capability where it reached 63 cm.

A. STRENGTH MUSCLES

From Appendix A, the graphs describe the average signal for each FSR sensor during above knee strength muscle activities that are taken from five M subjects while other study included ten subjects (5 male and 5 female) [12]. The duration of the experiment to record the signals for each activity is ten seconds. It is noted that the signal of all FSR sensors from
F1 to F8 started at approximately the same value (800) as an analog voltage which is near the maximum value (1023) except for FSR 1-subject 4 (F1-S4), F2-S5, F5-S2, F6-S1, F7-S4 AND F8-S4, where the signals started at lower values but not from the zero. This is due to the possibility that the cuff is somewhat narrow on the thigh. As mentioned earlier, F1 is located on the rectus femoris (RF) muscle as a reference position for all subjects. The graphs show no significant differences between the signals’ values except for F1-S4, F2-S (4 and 5), F3-S (4 and 5), F4-S (4 and 5), F5-S (2 and 4), F6-S (1,4 and 5), F7-S (4 and 5) F8-S (4 and 5) that record some fluctuations in the signal. There is a noticeable similarity between some of the signals because of the possibility that both sensors read the signal from the same muscle.

From Appendix B, the graphs describe the average signal for each FSR sensor during below-knee strength muscle activity. The sensor F1 for all subjects shows a signal starting at high value and records some fluctuations in the signal. This is located on the tibial anterior (TA) muscle as a reference position for all subjects, where S (1,2, and 5) signals are recorded as the highest peaks of values. There is also noticeable similarity between some of the signals, such as in F6 and F7 for all subjects. However, some signals are weak equal to zero, especially in F2-S (1,2, and 3), F3-S2, F4-S2, F5-S5, and F8-S (1 and 2), due to their non-conducive position to any muscular activity.

**B. GAIT CYCLE (NORMAL WALKING)**

In general, all subjects conducted gait cycle activity without any conditions speed [46], however the demographic data and activities from the subjects is well recorded and a reference to conduct the justification of activities for the muscle performance. From Appendix C, the graphs describe the average signal for each FSR sensor during gait cycle activity above-knee muscle, in which F1 is located on the rectus femoris (RF) muscle as a reference position for all subjects. As shown in the graphs, the readings for most signals start from a high value where the issue of tightening the cuff is repeated here. This issue appears from F1 to F8 for all subjects except F2 and F8 that are not in all subjects. This issue is observed too in the strength muscles activity. F2-S3 is the only sensor that shows a weak signal for all subjects because its position is not conducive to any muscular activity. Some of the muscle having two sensors to identify that the activities at same muscle but with a different position that can contributed to a difference muscle performance for the same muscle.

From Appendix D, the graphs represent the average signal for each FSR sensor during gait cycle activity below-knee muscle. F2 is the only sensor that shows a weak signal for all subjects, while F8-S2 is the only subject that records a weak signal. Their positions are not conducive to any muscular activity, same as F2-S3 in gait cycle activity above-knee muscle. The signals are more fluctuating compared with signals in gait cycle activity above-knee muscle.

**FIGURE 11. (a), (b), (c) and (d), are the average signal for each FSR sensor during above-knee strength muscle activity for all subjects.**

**IV. CONCLUSION**

The study set out to design a new reliable cuff system that can be used for testing the activation of muscles for prosthetic users especially those dealing with muscle verification such
as, rehab specialist, prosthetist and orthotist, and clinical engineer. The cuff was printed by using a FDM 3D printer using TPU and PLA material. Strength muscles and gait cycle i.e., normal walking activities were applied using the cuff system. It turned out that the cuff did not change its dimensions after its use in the experiments, which indicated the efficiency of the stretchable capability of the TPU material used in printing the cuff. There was no specific speed fixed for these activities but was determined by the abilities of each subject. The duration of the experiment to record the signals for each activity was ten seconds. According to the signals, F1- all subjects for both activities showed no significant change in
the signals and started from high values. That is from the effect of the cuff being tight on the limb. While F2 in both activities for almost all subjects represented weak signals because their positions were not conducive to any muscular activity. There is a need to reconsider the cuff size to avoid the issue of cuff tightness. In general, the experiments’ results showed the muscles’ active positions while showing the variation of the activity occurring in those positions. In contrast, the inactive positions were also represented in the results of the experiments. The is also needed to clarify more about...
FIGURE 16. (e), (f), (g) and (h) are the average signal for each FSR sensor during gait cycle (normal walking) above-knee muscle activity.

the interaction between the gait cycle kinetics and kinematics compare with the EMG performance.

APPENDIX A
The average signal for each FSR sensor during above-knee strength muscle activity for all subjects

APPENDIX B
The average signal for each FSR sensor during below-knee strength muscle activity for all subjects

APPENDIX C
The average signal for each FSR sensor during gait cycle (normal walking) above-knee muscle activity
The authors appreciate the subjects significant contributions of time and effort to this study.

FIGURE 18. (e), (f), (g) and (h) are the average signal for each FSR sensor during gait cycle (normal walking) below-knee muscle activity.

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