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A Pressure Sensation System Prototype for Upper Limb Amputation

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Abstract: *Sensational capability is extremely essential to human behavior and lets him achieve effective contacting with the natural world. Feedback Information from bionic arm is often really useful when it comes to identifying the defenses of the robot arm and maintaining interaction among user and machine. Scientific researches to restore feeling were via several methods. This research suggested a pressure sensation system, it transfers the pressure to a particular spot on human body skin from the end of bionic arm finger. The muscle simulator is used as actuator to produce equivalent feeling to the pressure at the end of finger. System was assessed and analyzed to achieve the desired result. The results confirm the ability to transfer the sense of pressure for the system user.*

Keyword: *Biomedical engineering; Embedded system; Pressure sensation; Prototype; Handicap.*

1. INTRODUCTION

Limb amputation is widespread than what most people know, and numbers increase with time. In the United States only, an approximate 1.7 million humans live with Limb Amputation with growth rate between 50 to 100 thousand each year [1]. And these numbers may increase or decrease based on the regions. Limb amputation handicaps require enhanced bionic limb with more acceptability for handicapped. Bionic limb must provide what user needs because approximately 21% of upper limb amputations do not use bionic arm for this reason. Also, absence of feeling in bionic arm consider as the reason for around 85% of them [2]. As a consequence, researchers are working to enhance and improve artificial limb compatibility. Including the sensation system helps the users to have some level of feeling and improve their using experience. Number of methods are used as sensation feedback for handicapped. Methods can be divided based on its requirements for a surgery.

A variety of feedback methods without surgery are developed by researchers. C. Cipriani [3] was using the vibrotactile method as a stimulus to the users. It is producing mechanical motion at specific point on the skin. In which, motion is generated by DC motor. Mechanical movement is equal to the gripping strength.

R. Prior [4] suggested signal-based gripping force stimulation, detected by sensors attaching to the hand. The level of force specifies the function of the stimulator's pulse width and repetition frequency of the pulse.

M. Paul [5] deploys a Peltier device as well as a pressure device to stimulate specific spot at skin of the user. Peltier device produces a feeling of temperature hot or cold which this device is producing in simultaneous decreasing in temperature on one side and increasing on the other. Changing current direction will switch the surface side from cold to hot and vice versa. Pressure feedback unit is based on McKibben pneumatic artificial muscle. Pneumatic artificial muscle is used as actuator for pressure device. In which it is connected to air pumps via the closed air channel that is controlled by controlling system. The level of pressure changing on the artificial muscle is determined by the amount of pressure that sensed and returned to the system.

Chiharu Ishii [6] developed a sensation system to simulate two feeling temperature and force sense. Temperature feedback sense is presented using Peltier device which it is mounted on the arm. Also, force feedback sense is presented using winding a belt connected to a motor.

Benjamin Stephens [7] mixed skin stretching and

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mechanical pressure to present feedback sense. Three servo motors are used, each of them is contained a mechanical crank. Cranks orientation are presenting skin stretch which can be recognize to determine the force.

Engels [8] studied mixing two different types of feedback sense. Audio biofeedback or vibrotactile feedback are combined with visual feedback. This mixing enhanced the functionality of grasping abilities.

Markovic [9] used augmented reality as feedback for the handicapped. Patient monitored grip strength, EMG intensity and other information for the prosthetic hand using Google glasses. The user employed visual feedback to enhance the interaction with the artificial arm.

Several surgical procedures have suggested giving a feeling of touching B. Nghiem [10] explored recent developments in sensory feedback, it also discussed using the advanced neural signaling technology in prosthetic sensory system for the future. Graczyk[11] introduced surgical Implantation for nerve electrodes. It is transferred artificial form of touch and proprioception, which are proportional to bionic arm sensors as shown in Figure 1. Force transducer is mounted on the bionic arm at the palm, middle finger, and index. A sensor was installed at the bionic arm to calculating the span of opening. The sensors transmitted analog signals to the Neurostimulator. It processes the received signal of pressure and arm opening state data to generate control signal, it is trains of stimulation pulse that sent to the stimulation points.

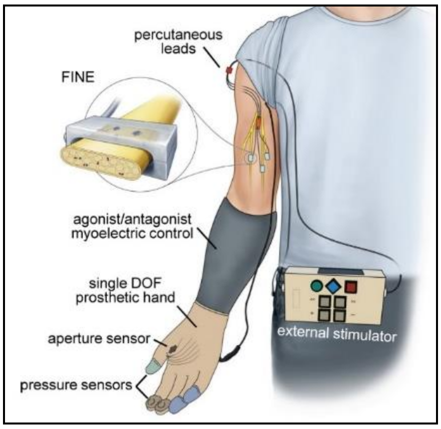


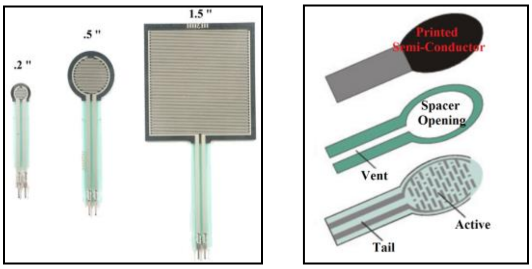
Figure 1: Schematic diagram of a home system for sensory restoration [12].

This work introduces a prototype of pressure sensation system to transfer stimulation signal from a robot arm to other healthy parts in handicap. Article organized in the following structure of sections: The Structural Design section presents the sensor and stimulator parts of the system. The Proposed Methodology section describes the system design and operation process. Results and Discussions section shows system response and confirm its ability to achieved the desirable response. Finally, the research is wrapped up with Conclusion.

2. THE STRUCTURAL DESIGN

System structure is consisting from three parts: force sensing resistor, muscle stimulator and some electrical components.

FSR is a low-cost sensor that has a capability to detect physical pressure. Its resistance changes based on the pressure or force that applied. When there is no applied pressure or force, resistance reaches its maximum value. On other hand, senor resistance value decreases corresponding to the decreased pressure applied on it. The sensor is made from two layers separated by spacer as shown in the Figure 2.b. When force is applied on the sensor, the particles in the layer contact the conducting electrodes on the other layer that will change the resistance of the sensor. Voltage divider circuit can be implemented for this sensor as a signal conditioning circuit [13].



(a) (b)

Figure 2: (a) FSR types. (b)FSR layer.

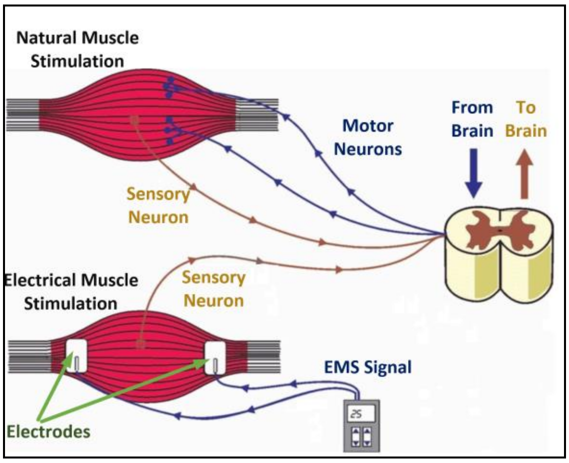


Figure 3: Electronic Muscle Stimulator.

Electronic Muscle Stimulator is a machine with the ability to contract human muscles. It generates electrical impulses when they pass through muscle will contract it. The device has two electrodes connected along the muscle body to stimulate it. Electrodes are

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pads that put on skin and have the ability to conduct electricity as shown in Figure 3. Electrical pulse mimics the signal that comes from the nervous system to cause muscle contract. EMS is used in different ways:

1. Muscle massage.
2. Decrease muscle spasms.
3. Reduce joint pain.
4. Enhance blood flow.
5. Prevent muscle atrophy.
6. Physical therapy.

3. THE PROPOSED METHODOLOGY

Pressure sensation system is used to transfer the pressure from the bionic arm fingers to the targeted points at a healthy part in the human body. Force Sensitive Resistor is used as a sensor to measure the force. This sensor works as a variable resistor based on the force. Voltage divider circuit introduces as an interfacing for Arduino board. FSR is connected between VCC source and the analog input of the Arduino. Also fixed resistor R equal to 10 kΩ connected between GND and the same analog input of the Arduino as shown in the Figure 4. Output voltage calculated based on the voltage divider law Equation 1.

$$Vo = VCC \times \frac{R}{R+FSR} \tag{1}$$

FSR changed value based on the force applied on it.

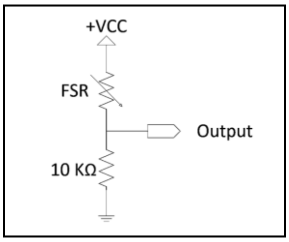

Figure 4: FSR interface circuit.

5V VCC is supported from the power source. When no force applied to the FSR, it's resistance value will be infinite. So, the output signal will be zero. On the other hand, if the force is maximum the output will be equal or close to 5V. Output signal is connected to the analog input at Arduino board. Arduino board processes the signal and mapped the signal to a new range. The signal is mapped in to new range data between 0 to 100. The resultant value refers to the pulse width modulation duty cycles which controls the switching circuit. When duty cycle equals to zero, this mean no electrical muscle stimulator signal. On the other hand, the 100% duty cycle means maximum electrical muscle stimulator generated. Signal is generated by a digital pin at Arduino. This signal controls the switching circuit which in turns controls the electrodes as shown in the Figure 5. Also, Arduino provides level of protection to bionic arm during processing the force. If the force exceeds the threshold, the arm holds out. Arduino sends interruption signal to protect the bionic arm.

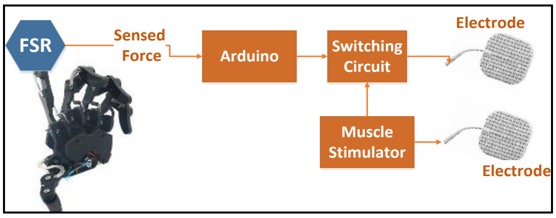

Figure 5: Block diagram for a single finger pressure sensation.

Switching circuit is constructed from two main parts. First, the optocoupler provides a level of protection between the control circuit and the actuation circuit. Second, MOSFET Switch Module controls intensity of the electrical muscle stimulator signal. Muscle stimulator generated electrical signal will flow out from electrode and back from the other. One electrode is connected directly to muscle stimulator. Other electrode is connected to the switching circuit then back to muscle stimulator. Pressure sensation circuit is shown in Figure 6.

Five pressure sensation system are used for the fingers within each bionic arm. As shown in Figure 7, the suggested armband comprises five pair of muscle stimulate electrodes that behave as actuators for the system.

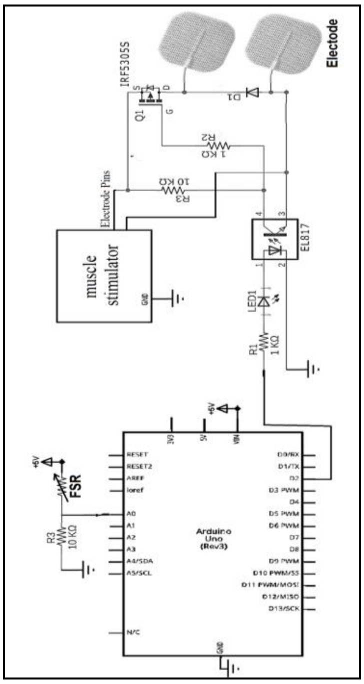

Figure 6: Single finger sensation circuit for pressure.

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Power was supported by a rechargeable battery. Arduino processes FSR signals of the bionic arm to protect the arm structure and the object that captured.

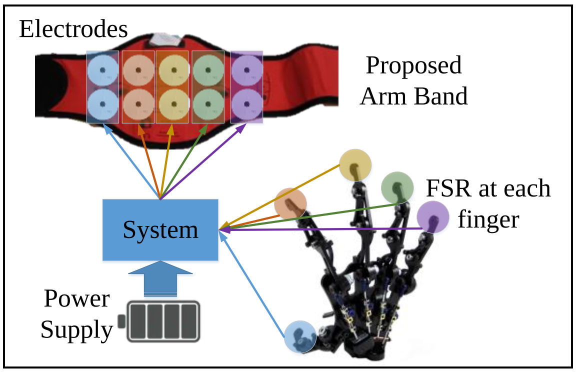

Figure 7. Block diagram for arm band sensation system.

4. RESULTS AND DISCUSSIONS

This section illustrates the implementation of the real-time pressure sensation system, which is successfully testing the hardware implementation and assessing the performance of the system. The system controls the muscle stimulator device to produce pressure feeling. The control system changes the strength of the muscle stimulator signal based on the FSR sensed value. FSR resistor changes its resistor proportional to the force applied on it. FSR connected with 10 Kohm resistor to form a voltage divider.10 Kohm resistor was selected based on the FSR specification in which the output of the signal conditioning becomes close to linearization. It is supported by 5v as a supply voltage.

The expected circuit output can be calculated based on the voltage divider Equation 1. Arduino board will process the sensor output value and generate PWM signal based on it. PWM signal will track the change in FSR signal. PWM signal with variable duty cycle simulates the different pressure on the arm. Pressure sensed signal is processed to map a range of intensity of muscle stimulator device. For monitoring purpose only, the sensed force digital value was scaled by dividing its value by 9 before displaying it. Arduino serial plotter was used to display the signal in real time manner. Figure 8 shows system response for gradually increasing of the force.

PWM signal is proportional to the change in the pressure sensation. Figure 9 shows the effective system response for rapid changes in the pressure sensed. Figure 10 shows perfect system response for tracking fast change in the pressure. Human response for a stimulation signal may differ from person to other. So, the signal strength can be changed to reach better result from the muscle stimulator device.

Statistical Pressure sensation test is performed by volunteers by considering steps. Each volunteer wears the arm band and performs different pressing pressure on the force sensing resistor.

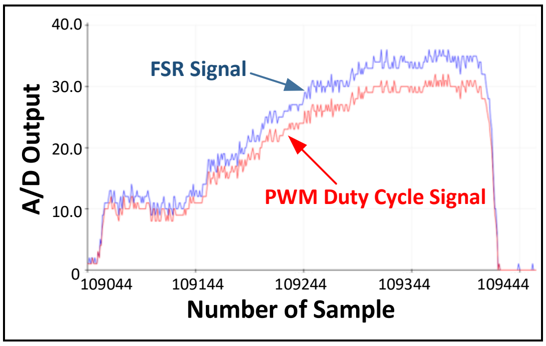

Figure 8: Pressure sensation system response.

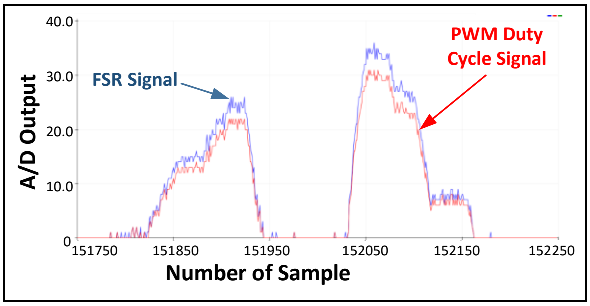

Figure 9: Pressure sensation system response for rabid change in pressure

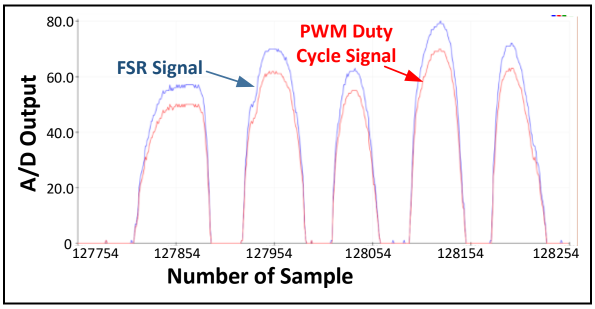

Figure 10: Pressure sensation system response for fast change in pressure.

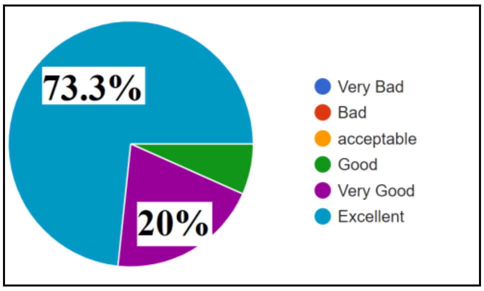

Figure 11: Volunteers response on the scale of self-acceptable to use the system.

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After completing the test, each volunteer expressed its response. Volunteers response on the scale of self-acceptable to use the system shown a good impact in which 93.3% over a very good impact as shown in Figure 11.

5. CONCLUSIONS

This article discusses a way of improving the interaction of the amputee with a bionic arm. Also, it offers a better experience of engaging with items that have different pressure withstanding. The research results indicate that the proposed system is capable of tracking the changing in the pressure at finger. Moreover, it is capably to produce alternative feel of pressure on the skin of the amputee at specific point. The techniques explained in this paper are easily adapted to so many bionic arms.

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Authors Biography

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Basil Sh. Mahmood was borne on 1953 in Mosul/ Iraq, graduated on 1976 form university of Mosul/ Electrical department in the field Electronics and Communications on 1979. Then he joined in Computer Center of the same university as assistant lecturer. Then after he got the degree of Ph.D. On microprocessors architecture on 1996. Now, he is a professor of microprocessors and computer architecture in Computer Engineering Department/ University of Mosul. He published with others 4 books and more than 50 research papers in many journals and conferences. He supervised more than 22 M.Sc. and 14 Ph.D. Students. His intersects are in microprocessors, computer architectures, image and signal processing, modern methods of Artificial Intelligence. He awarded many prizes and Medals.

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