BJES Basrah Journal for Engineering Sciences

Basrah Journal for Engineering Sciences, Vol. 24, No. 2, (2024), 62-67

Original Article

Journal homepage: www.bjes.edu.iq
ISSN (Online): 23118385, ISSN (Print): 18146120

Design and Implementation of an Upper Limb Prosthetic Hand Using a Pressure Sensor

Ahmed M. Al-Khazzar [1, *], Jabbar S. Hussain [2], Mithaq Nama Raheema [3]

[1,2,3] *Department of Prosthetics and Orthotics Engineering, College of Engineering, University of Kerbala, Kerbala, Iraq*
E-mail addresses: ahmed.m.ahmed@uokerbala.edu.iq , jabbar.salman@uokerbala.edu.iq , methaq.n.rhiama@uokerbala.edu.iq
Received: 22 April 2024; Accepted: 10 July 2024; Published: 17 August 2024

Abstract

Smart prostheses hands have seen vast advancement in recent years. Amputees with upper hand loss have better access to intelligent prostheses that help them with their daily life activities. Smart prostheses however are still in development and have a few disadvantages, such as being expensive, complex, require training and being error prone in some cases. In this paper a simple, cost effective, practical upper limb prosthetic device is proposed that uses pressure sensors to acquire the action intent from the amputees. The pressure sensor serves as input signal to the Control Unit (CU). Using a selector keyboard, the amputee can choose between five predefined movements. The advantages of the proposed system compared to other prostheses using EMG, EEG, Voice is design simplicity and cost. The approximate cost of the proposed prosthetic hand is less than 200$. In addition, some of the complexities and error prone properties of the other alternatives are avoided and less probability of use fatigue is achieved.

Keywords: Active prosthesis, Electromyography, EMG, Pressure sensors, Prosthetics, Upper limb.

https://doi.org/10.33971/bjes.24.2.8

1. Introduction

Healthy people usually underestimate their ability to perform essential physical activities such as picking up various objects, walking and sprinting. For many amputees worldwide, these abilities are inaccessible. The National Center for Health Statistics in United States reports that in 2022, 18.5% of adults suffered from difficulties in physical activities [1]. It is estimated that more than 40,000 are people who suffer from hand amputation. Recent engineering advancements provided a means to improve the lifestyle of those amputees in meaningful ways. Some examples are various types of smart functional upper limb prostheses. However, there is still a long path before those protheses become widely available. The current cutting-edge prostheses can be very expensive and not very efficient in terms of functionality and user training difficulties [2].

Most current prostheses use a sensing method to understand the patient’s intent and then send this intent to actuators performing a physical activity. These sensing methods include but are not limited to surface electromyography signals (sEMG) [3]-[7], electroencephalogram (EEG) [8]-[12], voice [13]-[15] and muscle movement (passive body powered prosthesis) [16]. In this section some of drawbacks of these sensing methods are presented.

Asyali et al. [3] suggested that EMG signals can have disadvantages such as requiring high effort from the patients and could cause early tiredness problems. The paper suggested using voice commands instead and proposes the design of a multi-fingered prosthesis hand that can pick up and release various objects. The proposed system included 3 motors and gears as actuators to move the prosthesis. A speech recognition module is utilized as a sensing method to control the hand.

An EEG based controlled prosthetic hand system is proposed by Bright, Dany et al. [8]. It could be used in cases with severe disabilities where EMG sensors and voice commands could not be used. They introduce a brain controlled prosthetic arm that uses Neurosky Mindwave headset to control two gestures (opening and closing of hand). The captured brain signals were used as a sensing method to instruct the movements of the servo motors. They claimed an accuracy rate of 80% and suggested a low-cost system that could be used in cases with severe disabilities to control the prosthetic arm of patients.

Huseein [13] suggested using voice commands as a means to control the electrical motors of the prostheses. It used Neural Network (NN) with Radial Basis Function (RBF) to classify the received voice commands. They achieved a recognition rate of more than 90%.

Pressure sensors are used for different applications in prosthetic devices such as aiding in grasping objects, interacting with delicate objects, and monitoring the inner socket environment [15]. For example, Chuanyang et al. [16] used a capacitive sensor with proximity and force detection capabilities to design an intelligent prosthetic hand that is able to perform accurate grasping. The capacitive sensor contains copper foil electrodes which can identify objects from a distance of 100 mm and measure forces of up to 12 N. They describe the implemented system as capable of accomplishing complex control of prosthesis hand.

Tabor et al. [17] proposed using a capacitive pressure sensor to identify and monitor the inner socket environment to provide a more comfortable and a better fit for sockets. Wearing prosthetic devices for extended periods of time can cause discomfort for the amputee. A textile capacitive sensor is used in the region between the residual limb and the socket to monitor the area.

Most commercial prosthetic limbs use sEMG sensors as the means to capture the user's intent. The sEMG systems can provide acceptable accuracy in controlling the prostheses, however, EMG signals are susceptible to noise from different sources such as skin impedance, power grid, etc. This noise can cause the prosthetic to move unintentionally or vibrations in the movement [15, 18, 19]. The past literature suggests that, an array of pressure sensors can be utilized to sense muscle movements and discover the user intent to move the prosthetic hand [19].

In order to overcome the aforementioned problems, the objective of this paper is to present the design and implementation of a simple, cost effective, practical upper prosthetic hand that uses a pressure sensor as a trigger to acquire the action intent from the amputees. The pressure sensor can be placed between the Flexor Carpi Ulnaris muscle of the residual body part and the socket. The proposed system will use a selector keyboard, to enable the amputee to choose between six predefined movements, namely "fingers open", "fingers closed", "half open (grasp)", "hand shake", "OK", and "grabbing objects". The aim is to implement a prosthetic hand that acquire the use intent more accurately and introduce less fatigue for the patient.

The proposed system is designed to overcome the limitations of the current control mechanisms in prosthetic hands (such as EMG, EEG, and voice) by being less error prone, easier to use (by the addition of the keyboard), and causing less fatigue for the amputee since it does not require high muscle activity and or concentration to operate.

2. Materials and methods

2.1. Pressure sensors

The pressure sensor uses the analogue change in resistance to measure the applied pressure. The external pressure modifies the value of the resistance and subsequently the measured voltage signal can be used as a pressure value indicator. The sensor uses a thin film of flexible pressure material that is waterproof. Figure 1 shows the pressure sensor, and Fig. 2 shows the Arduino interface. The sensor specifications are shown in Table 1.

Table 1. The pressure sensor specifications [20].

Parameter	Values	Unit
Range	0 to 0.5	kg
Thickness	< 0.25	mm
Response point	< 20	g
Repeatability	< 5.8% on 50% load	-
Accuracy	2.5% - 85% range interval	-
Durability	100,000	times
Response time	< 1	ms
Recovery time	< 15	ms
Voltage	3.3 - 5	V DC
Working temperature	-20 to 60	°C
Electro Magnetic Interferenc	None	-
Electro static discharge	Non sensitive	-
Cost	~ 5	$

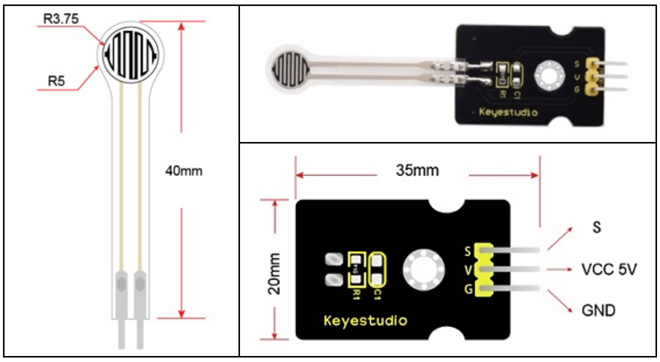

Fig. 1 Pressure sensor [20].

2.1. Control Unit (CU)

The control unit used in the work is the Arduino UNO. Arduino UNO is a cheap microcontroller that can generate Pulse Width Modulation (PWM) signals required to drive the servo motors accurately. Figure 2 shows the Arduino UNO connected to the pressure sensor [20].

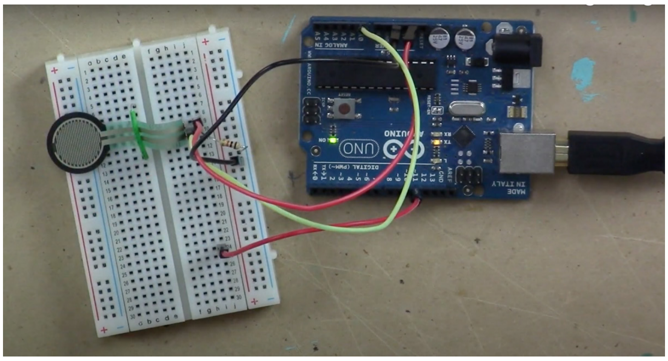

Fig. 2 Arduino interface with the pressure sensor.

2.3. Servo motors

The servo motor used to move the fingers of the prosthetic hand designed in this paper is an SG servo motor that can lift up to 6.5 kg/cm of load. The motor receives a PWM signal from the Arduino to determine the rotation angle and to move the fingers accordingly. Figure 3 shows the servo motor used in this work. The specifications of the servo motor are shown in Table 2 [21].

Fig. 3 Servo motor.

Table 2. The servo motor specifications [21].

Parameter	Values
Power	4.8 - 6 V DC
Average Speed	0.2 sec / 60 degrees @ 4.8 V, 0.16 sec / 60 degrees @ 6 V
Weight	39 g
Torque	5.5 kg/cm @ 5 V, 6.5 kg/cm @ 6 V
Size	40 mm, 20 mm, 38 mm ($L \times W \times H$)
Spline count	25

2.4. Selector keyboard for Arduino

In order to provide multiple gesture movements to the prosthetic hand a selector keyboard is used. The selector keyboard in a 1 × 5 matrix array with 5 keys as shown in Fig. 4. The keyboard provides a means for the user to choose the required action [22].

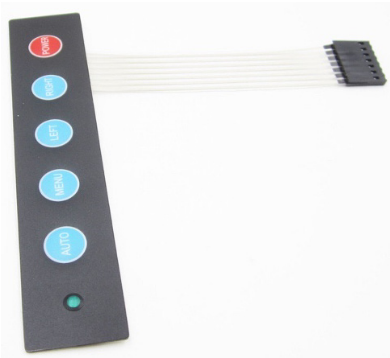

Fig. 4 The selector keyboard.

2.5. The prosthetic hand

A 3D printed hand is used in this work as shown in Fig. 5. It has five fingers with two servo motors that control the movements of the thump and the four fingers respectively. The 3D design of the prosthetic hand was used from the reference [23]. The hand provides several movements with the help of the servo motors.

Fig. 5 The 3D printed prosthetic hand.

2.6. Movement setup

According the required movements, the amputee uses the selector keyboard to choose the actions shown in the Table 3. The servo motors realize the movement by rotating by the angles defined in the table.

Table 3. Prosthetic hand movements.

No.	Movement name	Thump angle	Fingers angle
1	Fingers open	0°	0°
2	Fingers closed	180°	180°
3	Half open (grasp)	90°	90°
4	Hand shake	90°	0°
5	OK gesture	0°	180°
6	Grab an object	30°	35°

2.7. Methodology

The electrical components mentioned previously are assembled as shown in Fig. 6. The servo motors are placed inside the 3D prosthetic hand and connected to the fingers by strings to perform the required movements. One servo motor control the thumb finger and the other controls the four remaining fingers. The servo motors, selector keyboard, and the pressure sensor are connected to the Arduino. The pressure sensor is placed between the Flexor Carpi Ulnaris muscle of the residual body part and the socket. When the patient contracts the muscle, the pressure sensor will be triggered and sends a signal to Arduino.

The amputee is able to select the required action with the keyboard and then triggering the action by the interaction with the pressure sensor using his muscles. The prosthetic hand responds with that required movement. The final prosthetic hand is shown in the Fig. 6.

The following algorithm is used to perform the required steps for the task.

1. Start.
2. Movement needed is set by user through the selector keyboard (Each of the keys is connected to one of the analogue inputs of the Arduino. A set of conditional statements in the code can detect the chosen movement).
3. Monitoring the pressure sensor for the amputee activity. The pressure sensor is placed between the Flexor Carpi Ulnaris muscle of the residual body part and the socket. It can be activated by any small muscle pressure. (The input pin is monitored for values between 0 and 1023. Any value greater than ~30 is a command).
4. According to the pressor sensor value, the PWM signals are sent to the servo motors to move the fingers as needed (The servo.h library is used to send angle values to the servo motors to achieve the required movement).
5. Return to monitoring of the pressure sensor for the amputee activity.
6. The user can change the selected movement through the selector keyboard.

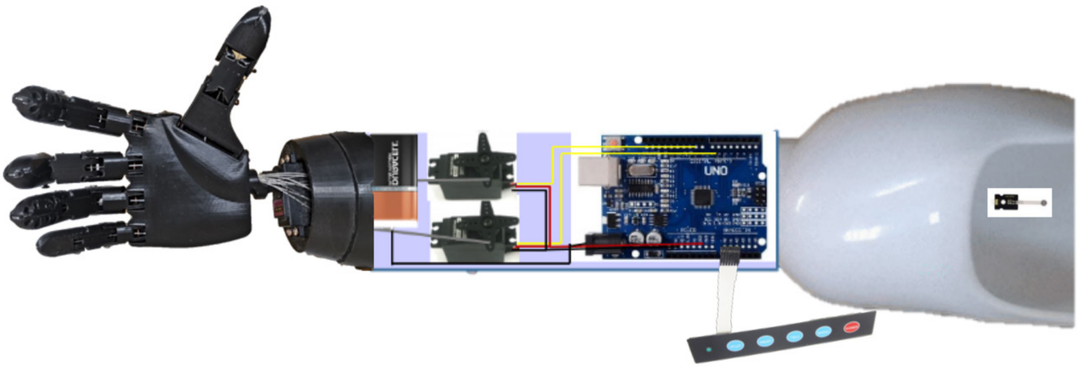

Fig. 6 The final prosthetic hand.

3. Results and discussion

The implemented pressure-based prosthesis is able to sense the required intent of the patient using the pressure sensor and perform the action specified by the user in the selector keyboard. The prosthetic hand movements in addition to the grabbing of a bottle using the prosthetic hand as in Fig. 7.

The justification for choosing the pressure sensor control mechanism is to avoid the limitations and drawbacks associated with the existing methods such as EMG [8, 9, 10], EEG [13], and etc. The used method in this paper can overcome problems such as misclassification of the movements because of the noise, the long training period to use the prosthetics. In addition, the proposed system is simple to use and cost efficient.

Table 4 shows the pressure sensor readings in various situations. The prosthetic hand senses any change in pressure and translates it to “On” state which in turn issues the relevant command selected by the selector keyboard.

Fig. 7 The prosthetic hand movements: (1) Hand shake, (2) Fingers closed, (3) Fingers open, (4) OK gesture, (5) Half open, and (6) Grabbing an object.

Table 4. Pressure sensor reading in different situations.

Pin reading	Pressure (grams)	Trigger On/Off
202	99	ON
310	151	ON
9	4	OFF
198	97	ON
560	273	ON
700	342	ON
520	254	ON
540	264	ON
500	244	ON
510	249	ON
690	337	ON
555	271	ON
583	285	ON
595	291	ON
507	248	ON
750	366	ON
502	245	ON
5	2	OFF
302	147	ON
410	200	ON
420	205	ON

Authors are not aware of a similar use of the pressure sensor in the previous literature. As previously stated in the introduction section, the application of the pressure sensor in prostheses in the past was mostly in aiding in grasping objects, interacting with delicate objects, and monitoring the socket for patient comfort. As far as authors are aware, the use of the pressure sensor as a control mechanism is not implemented before. The advantages of such a system over control mechanisms such as EMG, EEG, voice and etc. is its simplicity and cost. The approximate cost of the proposed prosthetics hand is less than 200$. In addition, some of the complexities and error prone properties of the other alternatives are avoided.

In comparison, EMG control systems are susceptible to noise from different sources such as skin impedance, power grid, etc. This noise can cause the prosthetic to move unintentionally or even vibrations in movement and cause frustration for the user [8, 9, 10].

The EEG control mechanisms are inherently complex and require the patient to wear the headset to control the prosthetic hand. Furthermore, accurate EEG devices are expensive [8]. This again can introduce unsatisfactory experience for the users. Finally, the voice-controlled prostheses while less obtrusive, may need a quite environment and require the patient to issue verbal commands that might interrupt the patient communications with the others while using the prosthetic hand [13]. The system proposed in this paper can overcome many of these problems.

For the future work it is recommended to use more advanced servo motors with less weight and smaller size. In addition, the mechanism to transfer the motion to fingers can be modified to use gear system instead of the strings which can provide a more stable and accurate motion. Finally, the use of more accurate and advanced pressure sensors can improve the controllability of the system. In addition, using multiple pressure sensors instead of one to improve the system sensitivity and usability for the patient.

4. Conclusions

In this work a practical upper limb prosthesis is designed and implemented that serves people with upper limb amputation. It provides the users a choice of five different movements by the use of a selector keyboard. A pressure sensor placed between Flexor Carpi Ulnaris muscle and the socket which served as a control mechanism to issue on/off triggers to the smart prosthesis. Six movements are available for the amputee, namely, fingers open, fingers close, OK gesture, hand shake, and half open, and grabbing an object. This movements are selected based on the most needed gestures for the amputee. Two servo motors have been used with high torque that serve as the actuators to move the fingers.

Amputees require significant training to learn to use most of the current professional prosthetics. In addition, the effort required and the accuracy of these systems are problematic. The authors believe that the current system can overcome a few of these limitations and thus improve the lives of the patients.

The advantages of the proposed system compared to other prostheses using EMG, EEG, Voice is design simplicity and cost. The approximate cost of the proposed prosthetics hand is less than 200$. In addition, some of the complexities and error prone properties of the other alternatives are avoided.

References

[1] Centers for Disease Control and Prevention, National Center for Health Statistics: Disability and functioning, 2017. https://www.cdc.gov/nchs/fastats/disability.htm

[2] Industrial Safety and Hygiene News, Statistics on hand and arm loss, 2014. http://www.ishn.com/articles/97844-statistics-on-hand-and-arm-loss

[3] M. H. Asyali, M. Yilmaz, M. Tokmakçi, K. Sedef, B. H. Aksebzeci, and R. Mittal, "Design and implementation of a voice-controlled prosthetic hand," Turkish Journal of Electrical Engineering and Computer Sciences, Vol. 19, Issue 1, pp. 33-46, 2011. https://doi.org/10.3906/elk-0912-315

[4] M. Alizadeh-Meghrazi, G. Sidhu, S. Jain, M. Stone, L. Eskandarian, A. Toossi and M. R. Popovic, "A mass-producible washable smart garment with embedded textile EMG electrodes for control of myoelectric prostheses: A pilot study," Sensors, Vol. 22, Issue 2, 2022. https://doi.org/10.3390/s22020666

[5] J. Park, J. Jeong, M. Kang et al., "Imperceptive and reusable dermal surface EMG for lower extremity neuro-prosthetic control and clinical assessment," npj Flexible Electronics, Vol. 7, Issue 1, 2023. https://doi.org/10.1038/s41528-023-00282-z

[6] D. Yadav and K. Veer, "Recent trends and challenges of surface electromyography in prosthetic applications," Biomedical Engineering Letters, Vol. 13, pp. 353-373, 2023. https://doi.org/10.1007/s13534-023-00281-z

[7] G. Paddam, V. Francis, N. Kumar, "AI Control of EMG Sensor Data for 3D Printed Prosthesis Hand. In: Sharma, V. S., Dixit, U. S., A. Gupta, R. Verma, V. Sharma, (eds) Machining and Additive Manufacturing. CPIE 2023. Lecture Notes in Mechanical Engineering. Springer, Singapore, 2023. https://doi.org/10.1007/978-981-99-6094-1_8

[8] D. Bright, A. Nair, D. Salvekar and S. Bhisikar, "EEG-based brain controlled prosthetic arm," 2016 Conference on Advances in Signal Processing (CASP), Pune, India, pp. 479-483, 2016. https://doi.org/10.1109/CASP.2016.7746219

[9] E. O. Ige, A. Adetunla, A. Awesu, and O. K. Ajayi, "Sensitivity Analysis of a Smart 3D-Printed Hand Prosthetic," Journal of Robotics, Vol. 2022, pp. 1-9, 2022. https://doi.org/10.1155/2022/9145352

[10] I. A. Satam, "A comprehensive study of EEG-based control of artificial arms," Vojnotehnički Glasnik, Vol. 71, Issue 1, pp. 9-41, 2023. https://doi.org/10.5937/vojtehg71-41366

[11] R. K. Kanna, S. P. A. Surendhar, M. R. AL-Hameed, A. M. Lafta, R. Khalid and A. Hussain, "Smart Prosthetic Arm Using Cognitive Application," 2023 3rd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), Greater Noida, India, pp. 1330-1334, 2023. https://doi.org/10.1109/ICACITE57410.2023.10182794

[12] J. Singh, F. Ali, R. Gill, B. Shah and D. Kwak, "A Survey of EEG and Machine Learning-Based Methods for Neural Rehabilitation," in IEEE Access, Vol. 11, pp. 114155-114171, 2023. https://doi.org/10.1109/ACCESS.2023.3321067

[13] J. S. Huseein, "Design and Implementation of Artificial Upper Limbs Based on Arabic Speech Words," Kerbala Journal for Engineering Science, Vol. 0, Issue 2, pp. 68-81, 2020. https://kjes.uokerbala.edu.iq/article_167156.html

[14] A. D. Abdul-nafa, S. S. Ahmed, Y. Ahmed, and O. M. Alsaydia, "Control Robotic Hand Depending on Voice Commands and IoT," Nano Biomedicine and Engineering, Vol. 15, Issue 3, pp. 288-295, 2023. https://doi.org/10.26599/nbe.2023.9290028

[15] N. Beauchamp, S. Chen, and M. Zhang, "Pressure Detection: Improving Prosthetics Efficacy," Final Report for ECE 445, Senior Design, Fall 2017, Project No. 21, 13 December 2017. https://www.seas.upenn.edu/~sihaoc/asset/senior-project-report.pdf

[16] C. Ge, B. Yang, L. Wu, Z. Duan, Y. Li, X. Ren, L. Jiang, and J. Zhang, "Capacitive sensor combining proximity and pressure sensing for accurate grasping of a prosthetic hand," ACS Applied Electronic Materials, Vol. 4, Issue 2, pp. 869-877, 2022. https://doi.org/10.1021/acsaelm.1c01274

[17] J. Tabor, T. Agcayazi, A. Fleming, B. Thompson, A. Kapoor, M. Liu, et. al., "Textile-Based Pressure Sensors for Monitoring Prosthetic-Socket Interfaces," in IEEE Sensors Journal, Vol. 21, Issue 7, pp. 9413-9422, 2021. https://doi.org/10.1109/JSEN.2021.3053434

[18] S. Micera, J. Carpaneto, and S. Raspopovic, "Control of hand prostheses using peripheral information," IEEE Reviews in Biomedical Engineering (R-BME), Vol. 3, pp. 48-68, 2010. https://doi.org/10.1109/RBME.2010.2085429

[19] R. Kõiva, E. Riedenklau, C. Viegas and C. Castellini, "Shape Conformable High Spatial Resolution Tactile Bracelet for Detecting Hand and Wrist Activity," 2015 IEEE International Conference on Rehabilitation Robotics (ICORR), Singapore, pp. 157-162, 2015. https://doi.org/10.1109/icorr.2015.7281192

[20] Keyestudio Thin-film Pressure Sensor for Arduino. https://www.keyestudio.com/products/keyestudio-thin-film-pressure-sensor-for-arduino

[21] Standard Servo-TowerPro SG-5010-5010, adafruit. https://www.adafruit.com/product/155

[22] LED 1 × 5 Matrix Array 5 Key Membrane Switch Keypad Keyboard for Arduino, alexnld. https://alexnld.com/product/led-1x5-matrix-array-5-key-membrane-switch-keypad-keyboard-for-arduino/

[23] Ikram, Ahmed; 3D Printed EMG Prosthetic Hand. https://www.instructables.com/3D-Printed-EMG-Prosthetic-Hand