Journal of Electronics and Informatics (ISSN: 2582-3825)
www.irojournals.com/iroei/

Emotionally Intelligent Next-Generation Touch-Controlled Prosthetic Hand

Abhirami J S.[1]**, Richard R.**[2]**, Muhammed Ajilan P T.**[3]**, Mahendran S.**[4]

[1]Assistant Professor, [2,3,4]UG Students, Department of Artificial Intelligence and Data Science, Nehru Institute of Engineering and Technology, Anna University, Coimbatore, India

E-mail: [1]nietjsabhirami@nehrucollages.com

Abstract

The research aims to develop an affordable and functional prosthetic hand with tactile feedback capabilities, addressing the challenges faced by individuals with upper limb differences. Through the integration of advanced sensing technologies such as EMG sensors and vibration motors, the prosthetic hand enables users to experience tactile sensations while grasping or interacting with objects. The design prioritizes modularity, adjustability, and lightweight materials to ensure a comfortable and customizable fit for a diverse range of users. Additionally, the prototype incorporates user-friendly interfaces and accessible components for ease of maintenance and repair. Through iterative testing and refinement, the proposed prosthetic hand seeks to provide a user-centered solution that enhances functionality, usability, and affordability in prosthetic hand technology. Ultimately, the prosthetic hand aims to empower individuals with upper limb differences by restoring dexterity and sensory perception, improving their quality of life, and fostering greater independence in daily activities.

Keywords: Prosthetic Hand, Tactile Feedback, EMG Sensors, Affordable, User-Centered

1. Introduction

The research endeavors to revolutionize the landscape of prosthetic technology by introducing an innovative prosthetic hand with tactile feedback capabilities at an unprecedented level of affordability. The development of this prosthetic hand is a response to the pressing

DOI: https://doi.org/10.36548/jei.2024.3.002
Received: 20.05.2024, received in revised form: 18.06.2024, accepted: 01.07.2024, published: 12.07.2024

need for accessible solutions for individuals with upper limb differences, who often face barriers due to the high cost of existing prosthetic options. By integrating advanced sensing technologies such as EMG sensors and vibration motors, the proposed prosthetic hand enables users to experience tactile sensations while interacting with objects, enhancing their sense of touch and improving their overall dexterity. The design focuses on modularity, adjustability, and lightweight materials to ensure a comfortable and customizable fit for users. The proposed design aims to empower individuals with upper limb differences, providing them with a prosthetic solution that not only restores functionality but also enhances their quality of life and allows greater independence in daily activities [3,4].

2. Literature Review

Belter and Dollar et al. [1] investigates the performance characteristics of anthropomorphic prosthetic hands by evaluating their dexterity, grip strength, and control mechanisms. They use standardized tests to measure these parameters and conclude that a balance between functionality and ease of use is crucial for effective prosthetic design.

Birglen and Gosselin et al [2] analyzes the grasp-state plane of underactuated fingers, which are essential for creating prosthetics that can adapt to different object shapes without complex control systems. They employ mathematical modeling and simulations to study the kinematics and dynamics of these fingers, demonstrating that underactuated designs can achieve stable grasps with fewer actuators.

Carbone et al. [5] compares the performance of the Federica and LARM hands through experimental testing. They assess factors such as grip force, energy consumption, and adaptability to various tasks. The results show that the Federica hand performs better in terms of energy efficiency and adaptability, while the LARM hand excels in grip strength.

Carrozza et al. [16] presents the development of a novel prosthetic hand, incorporating ongoing research and preliminary results to improve dexterity and user comfort. They utilize advanced materials and innovative actuation mechanisms, finding that their design enhances the hand's range of motion and grip precision .

Castro et al. [17] investigated the selection of suitable hand gestures for reliable myoelectric human-computer interfaces. They conduct experiments to identify gestures that provide high recognition accuracy and user comfort. Their results suggest that specific gestures can significantly improve the reliability and efficiency of myoelectric interfaces.

Chan and Englehart et al [6] proposed using hidden Markov models (HMM) for continuous myoelectric control. They train the HMM on myoelectric signals collected from muscle contractions, enabling the model to predict the user's intended movements accurately. Their results indicate a significant improvement in the control smoothness and accuracy of powered prostheses.

Chang et al.[7] contributed to prosthetic design by creating creative mechanisms that enhance the mechanical performance of prosthetic hands. They use CAD modeling and finite element analysis to optimize the design for strength and durability, resulting in a prosthetic hand that can withstand higher loads and provide more robust performance.

Ciocarlie et al. [8] introduced a soft finger model with adaptive contact geometry for improved grasping and manipulation. They use computational simulations and physical prototypes to test the model's effectiveness in handling various objects. Their results show that the adaptive contact geometry significantly enhances the versatility and reliability of prosthetic hands in performing complex tasks.

Dechev et al. [9] introduced multiple fingers and passive adaptive grasp mechanisms for prosthetic hands. They design and test a prototype that uses compliant joints and adaptive mechanisms to conform to various object shapes. Their results show that this approach reduces the cognitive load on users and improves the versatility of the prosthetic hand.

Ehrsson et al [10].explored the psychological integration of prosthetics with the user’s body image through experiments where upper limb amputees experience a rubber hand as their own. Using a combination of visual, tactile, and proprioceptive inputs, they find that users can be induced to perceive the prosthetic as part of their own body, which has significant implications for prosthetic acceptance and comfort.

Fukuda et al. [11]developed a human-assisting manipulator that is teleoperated by EMG signals and arm motions. They create a system that interprets muscle signals to control the manipulator's movements, enhancing the precision and responsiveness of the device. Their experiments show that this method provides intuitive and effective control for users.

Geng et al. [12] conducted a pilot study on EMG pattern-based classification of arm functional movements. They use machine learning algorithms to classify different arm movements based on EMG signals. Their findings indicate that accurate classification of these movements can improve the control strategies for prosthetic devices, making them more user-friendly.

Castellini and Smagt et al [13] explored the use of surface EMG in advanced hand prosthetics. They examine the challenges and benefits of using surface EMG signals to control prosthetic hands, focusing on signal acquisition and processing techniques. Their study highlights the potential of surface EMG to provide detailed and responsive control for advanced prosthetic devices.

Parker et al. [14] delve into myoelectric signal processing, which is crucial for interpreting the user's intent through muscle signals. They developed algorithms to filter and amplify these signals, improving the signal-to-noise ratio and enabling more reliable prosthetic control. Their findings demonstrate that enhanced signal processing techniques can lead to more responsive and intuitive prosthetic limbs.

Kyberd et al. [15]provide insights from a survey of upper-extremity prosthesis users in Sweden and the UK. They collect data on user satisfaction, common issues, and desired improvements, highlighting the need for better comfort, reliability, and functionality in prosthetic designs. Their findings underscore the importance of user-centered design in prosthetic development.

3. Methodology

The materials and methods used in the proposed design encompass a multidisciplinary approach aimed at achieving functionality, affordability, and user-centered design in the development of the prosthetic hand with tactile feedback capabilities. For materials selection, lightweight and durable components are prioritized to optimize functionality while minimizing weight and bulkiness. Advanced materials such as carbon fiber, lightweight metals, and 3D-printed polymers are chosen for their strength-to-weight ratio and suitability for prosthetic applications. These materials ensure the prosthetic hand is robust and resilient while remaining lightweight and comfortable for users to wear.

In terms of methods, the proposed design employs a combination of sensor integration, 3D modeling and printing, and iterative prototyping to develop the prosthetic hand. EMG sensors are integrated into the design to detect muscle signals and translate them into control commands, enabling intuitive and responsive operation of the hand. Vibration motors are also incorporated to provide tactile feedback to users, enhancing their sense of touch and improving overall dexterity. The design process involves extensive CAD modeling and simulation to optimize the ergonomics and functionality of the prosthetic hand. Parametric design tools are utilized to customize the hand to fit individual user requirements, ensuring a comfortable and secure fit for a diverse range of users.

Prototypes are fabricated using 3D printing technology, allowing for rapid iteration and refinement of the design. User feedback and usability testing are conducted throughout the development process to validate the performance and functionality of the prosthetic hand. This iterative approach enables continuous improvement and optimization of the design based on user needs and preferences. Overall, the materials and methods employed in the proposed are guided by the principles of functionality, affordability, and user-centered design, with the ultimate goal of providing individuals with upper limb differences access to a high-quality prosthetic solution that enhances their quality of life and fosters greater independence in daily activities.

3.1 Flowchart

The flowchart of the proposed work is illustrated in Figure 1 below.

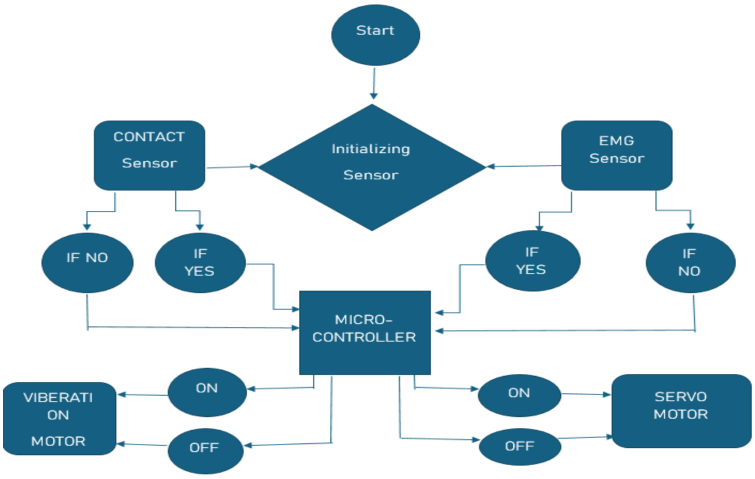


Figure 1. Flowchart

A user with a limb difference wears the prosthetic hand equipped with EMG sensors, a limit switch, servo motors, vibration motors, and an Arduino Uno microcontroller. As the user attempts to grasp an object, the EMG sensors detect electrical signals generated by muscle contractions in their residual limb. These signals are transmitted to the Arduino Uno, which interprets them to determine the user's intended hand movements. If the muscle activity surpasses a predefined threshold, indicating the user's desire to close the hand, the Arduino Uno sends signals to the user's desire to close the hand, the Arduino Uno sends signals to the servo motors to articulate the fingers and close the hand around the object with the appropriate force. Simultaneously, the limit switch monitors the hand's position. When the hand successfully grasps the object, the limit switch is activated, signaling the Arduino Uno to stop the closing motion. At this point, the vibration motors may be activated to provide tactile feedback to the user, confirming the successful grasp. The user can then manipulate the object as desired.

During this process, the Arduino Uno continuously monitors sensor inputs and adjusts motor actions in real-time, ensuring precise and coordinated movements. After completing the task, the user can release the object by relaxing their muscles, prompting the EMG sensors to detect decreased activity and signal the Arduino Uno to open the hand, releasing the object. This scenario illustrates how our project enables intuitive and responsive control of the prosthetic hand, enhancing the user's independence and quality of life. The Table 1 below shows the components used in the proposed design and Table 2 shows the software components used.

Table 1. Hardware Components Used

S.no	Components	Model	Specification
1	Limit switch x2pcs	Omron SS-5GL	SPDT, 5A @ 125VAC, 3A @ 250VAC
2	EMG sensor x1pcs	MyoWare Muscle Sensor	Measures muscle activity via EMG, adjustable gain
3	Arduino uno board x1pcs	Arduino Uno R3	ATmega328P microcontroller, USB interface
4	Vibration motors x 4pcs	10 mm Vibration Motor	3V to 4.5V operating voltage, for haptic feedback

5	Mg996r servo motors x4pcs	TowerPro MG996R	High-torque digital servo, metal gears, 180° rotation
6	Power supply board 12v x1pcs	DC Power Supply Module 12V	-
7	Buck converter x2pcs	LM2596 Buck Converter	Input 3.2V to 40V, output 1.25V to 35V adjustable
8	H-W battery x2pcs	Li-ion 18650 Battery	3.7V nominal voltage, rechargeable
9	DC-DC connecter jack male and female x1pcs	DC Power Jack Connector	Barrel-type connector for power supply
10	Jumper wires	Varying length and colors	-
11	3D-printed parts	Custom-designed for prosthetic hand structure using CAD	-

Table 2. Software Components Used

S.no	Components	Purpose
1	Arduino IDE	Used for programming the Arduino Uno Board
2	SolidWorks with ANSYS Workbench	Used for 3D model development and finite element analysis
3	C programming	Used for developing the control algorithms and interfacing.
4	Auto cad 360 fusion and Cura	Used for Preparing 3D models for printing and optimizing settings
5	Arduino Serial Monitor	Used for Debugging and serial communication monitoring

Figure 2 below shows the circuit diagram of the proposed system, including components such as the limit switch, EMG sensor, Arduino Uno R3 board, vibration motors, MG996R servo motors, 12V power supply board, buck converter, H-W battery, DC-DC connector jack (male and female), jumper wires, and the 3D-printed parts. The diagram illustrates the pin configuration and the connections established among these components.

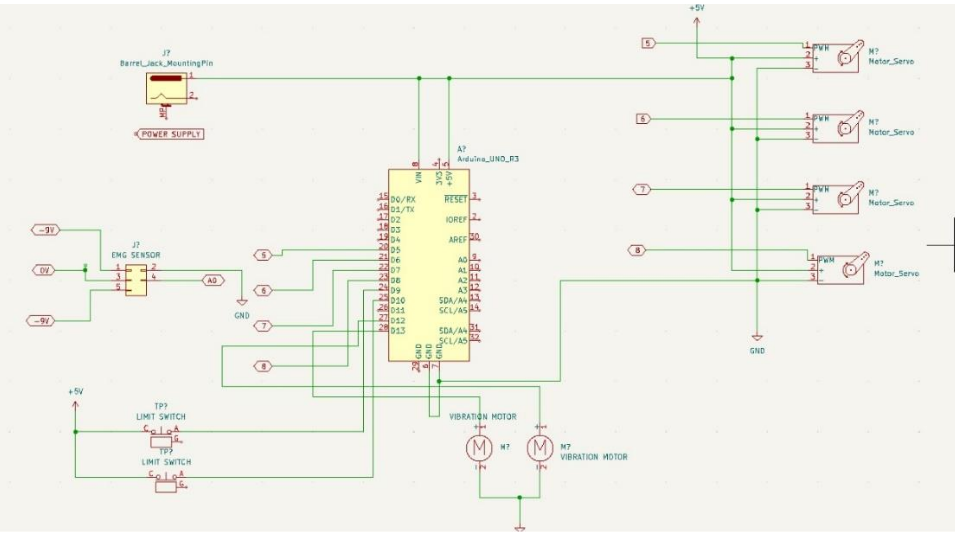


Figure 2. Circuit Diagram

3.2 Description

Power Suppley: This block supplies power to the entire system. The EPS32 is a microcontroller that likely controls the flow of electricity throughout the system.

Arduino UNO: The Arduino Uno microcontroller serves as the central processing unit in the proposed design, receiving input from sensors such as the EMG sensor and limit switch. It then processes this input to generate control signals for actuators like servo motors and vibration motors, facilitating intuitive and responsive control of the prosthetic hand.

EMG Sensor: The EMG sensor detects electrical signals generated by muscle contractions in the user's residual limb. These signals are transduced into voltage outputs proportional to muscle activity. The Arduino Uno processes these signals, enabling intuitive control of the prosthetic hand based on the user's muscle movements.

Limit Switch: The limit switch detects specific mechanical movements or positions in the prosthetic hand. When activated, it sends a signal to the Arduino Uno microcontroller, triggering corresponding actions or responses, such as initiating specific movements or activating other components like vibration motors, enhancing the functionality and user experience of the prosthetic hand.

Servo Motor: The servo motor receives signals from the Arduino Uno microcontroller to rotate to specific angles, enabling precise control of the prosthetic hand's movements. This motor's rotational motion is utilized to articulate various parts of the hand, allowing for coordinated and dexterous manipulation of objects.

Vibration Motor: The Vibration motors are connected to the micro-controller with the help of connecting wires. This vibration motor will be activated whenever the micro-controller gets input signal from the limit switch. This helps the user to sense the objects.

Buck Converter: The buck converter is used here to convert the voltage from 12v to 6v to supply power to the servo motors. This module helps to supply a constant voltage to the servo motors.

H-W Battery: The high watt battery is used to power up the EMG sensor. The EMG sensor requires both positive voltage and negative voltage .so, the batteries are connected in series connection by using jumper wires.

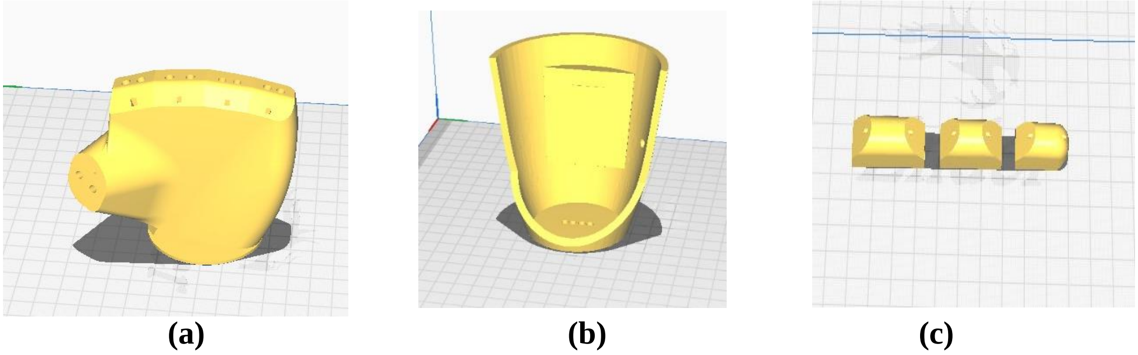
3D-Printed Parts: The 3D printed parts are designed using Auto cad 360 fusion and the designed parts are sliced using cura slicer and then it is printed using creality ender 3 using PLE filament.

The Table. 3 below shows the parameter and the values used designing the 3D parts

Table 3. Design Parameters

Parameter	Parts	Values	Description
Length	Finger Length (proximal, middle, distal)	5cm, 4 cm, 3 cm	Dimension of the length are defined
Angles	Angles at the knuckles and other articulation points.	00 to 900	Rotation constraints are set
Size	Palm Size	Width: 7 cm, Length: 10 cm	Width, length, and curvature of the palm are fixed
Grip Strength		5 N, 10 N, 15 N	Influence design for material strength and mechanics
Moving limits for joints	Range of motion and limitations at joints	Flexion: 0° to 120°	Motion constraints are set

The Figure 3 depicts the 3D Model of the proposed prosthetic hand design and Figure 4 shows the 3D printed part.



(a) **(b)** **(c)**

Figure 3. (a),(b),(c) 3D Model

Figure 4. 3D Printed Part

4. Results and Discussion

The proposed hand has been successful in achieving its objectives and delivering a prosthetic hand with an integrated system that enables intuitive and responsive control. Through meticulous design, testing, and iteration, we have established a workflow that seamlessly integrates EMG sensors, limit switches, servo motors, vibration motors, and an Arduino Uno microcontroller to create a prosthetic hand that meets the needs and expectations of its users.

The implementation of EMG sensors allows for the detection of muscle signals, enabling users to control the prosthetic hand with natural movements. Limit switches provide additional input signals, ensuring precise and coordinated actions of the hand in response to user interactions. Servo motors articulate the fingers and hand parts, facilitating the grasping and manipulation of objects, while vibration motors provide tactile feedback to enhance the user experience.

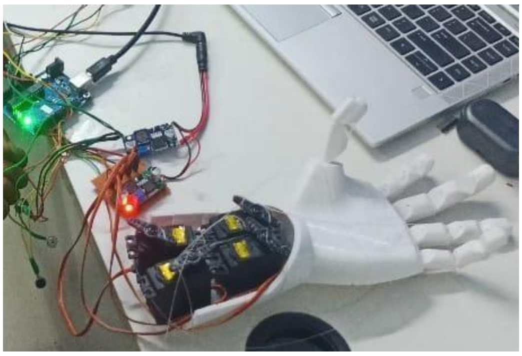


Figure 5. Prosthetic Hand

The development of the prosthetic hand (Figure 5) with tactile feedback capabilities at an affordable cost, represents a significant advancement in the field of prosthetics. By integrating advanced sensing technologies such as EMG sensors and vibration motors. The prosthetic hand aims to provide users with a more intuitive and sensory-rich experience. This innovative approach addresses the pressing need for accessible prosthetic options for individuals with upper limb differences, who often face barriers due to the high cost of existing prosthetic solutions.

One of the key challenges in prosthetic design is balancing functionality with affordability. While high- end prosthetic devices offer advanced features, they are often prohibitively expensive, limiting access for many individuals. The proposed design seeks to bridge this gap by developing a prosthetic hand that not only restores functionality but also remains accessible to a wider range of users.

Overall, the development of the prosthetic hand represents a significant step forward in making prosthetic technology more accessible and inclusive. By prioritizing affordability, functionality, and user experience, we aim to empower individuals with upper limb differences and improve their overall well- being.

5. Conclusion

With the successful development of our prosthetic hand, the proposed design has achieved the primary objective of creating an affordable yet functional solution for individuals with upper limb differences. The success of the developed hand is evidenced by the prototype's ability to provide tactile feedback while remaining cost-effective, addressing a critical need in the prosthetics market. The iterative design and testing, ensures that the prosthetic hand is user-centered, customizable, and comfortable, enhancing its usability and overall user satisfaction.

The positive feedback received from users and stakeholders validates the effectiveness of the approach and highlights the importance of accessibility in prosthetic technology. By prioritizing affordability without compromising on functionality, significant strides are made towards empowering individuals with upper limb differences and improving their quality of life.

References

[1] J. T. Belter and A. M. Dollar, "Performance characteristics of anthropomorphic prosthetic hands," 2011 IEEE International Conference on Rehabilitation Robotics, Zurich, Switzerland, 2011, pp. 1-7,

[2] Birglen, Lionel, and Clément M. Gosselin. "Grasp-state plane analysis of two-phalanx underactuated fingers." Mechanism and Machine Theory 41, no. 7 (2006): 807-822.

[3] Bitzer, Sebastian, and Patrick Van Der Smagt. "Learning EMG control of a robotic hand: towards active prostheses." In Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA, Orlando, FL, USA, 2006., pp. 2819-2823. IEEE, 2006.

[4] Burck, James, Michael J. Zeher, Robert Armiger, and James D. Beaty. "Developing the world’s most advanced prosthetic arm using model-based design." The MathWorks News and Notes (2009): 1-4.

[5] Carbone, Giuseppe, Cesare Rossi, and Sergio Savino. "Performance comparison between FEDERICA hand and LARM hand." International Journal of Advanced Robotic Systems 12, no. 7 (2015): 90.

[6] Chan, Adrian DC, and Kevin B. Englehart. "Continuous myoelectric control for powered prostheses using hidden Markov models." IEEE Transactions on biomedical engineering 52, no. 1 (2004): 121-124.

[7] Chang, Wen-Tung, Ching-Huan Tseng, and Long-Iong Wu. "Creative mechanism design for a prosthetic hand." Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine 218, no. 6 (2004): 451-459.

[8] Ciocarlie, Matei, Claire Lackner, and Peter Allen. "Soft finger model with adaptive contact geometry for grasping and manipulation tasks." In second joint eurohaptics conference and symposium on haptic interfaces for virtual environment and teleoperator systems (WHC'07), pp. 219-224. IEEE, 2007.

[9] Dechev, Nikola, W. L. Cleghorn, and S. Naumann. "Multiple finger, passive adaptive grasp prosthetic hand." Mechanism and machine theory 36, no. 10 (2001): 1157-1173.

[10] Ehrsson, H. Henrik, Birgitta Rosén, Anita Stockselius, Christina Ragnö, Peter Köhler, and Göran Lundborg. "Upper limb amputees can be induced to experience a rubber hand as their own." Brain 131, no. 12 (2008): 3443-3452.

[11] Fukuda, Osamu, Toshio Tsuji, Makoto Kaneko, and Akira Otsuka. "A human-assisting manipulator teleoperated by EMG signals and arm motions." IEEE transactions on robotics and automation 19, no. 2 (2003): 210-222.

[12] Geng, Yanjuan, Long Yu, Miao You, and Guanglin Li. "A pilot study of EMG pattern based classification of arm functional movements." In 2010 Second WRI Global Congress on Intelligent Systems, vol. 3, pp. 317-320. IEEE, 2010.

[13] Castellini, Claudio, and Patrick Van Der Smagt. "Surface EMG in advanced hand prosthetics." Biological cybernetics 100 (2009): 35-47.

[14] Parker, P., K. Englehart, and Bernard Hudgins. "Myoelectric signal processing for control of powered limb prostheses." Journal of electromyography and kinesiology 16, no. 6 (2006): 541-548.

[15] Kyberd, Peter J., Constanze Wartenberg, Leif Sandsjö, Stewe Jönsson, David Gow, Joakim Frid, Christian Almström, and Lena Sperling. "Survey of upper-extremity prosthesis users in Sweden and the United Kingdom." JPO: Journal of Prosthetics and Orthotics 19, no. 2 (2007): 55-62.

[16] Carrozza, Maria C., B. Massa, Silvestro Micera, R. Lazzarini, M. E. Zecca, and Paolo Dario. "The development of a novel prosthetic hand-ongoing research and preliminary results." IEEE/Asme Transactions on Mechatronics 7, no. 2 (2002): 108-114.

[17] Castro, Maria Claudia F., Sridhar P. Arjunan, and Dinesh K. Kumar. "Selection of suitable hand gestures for reliable myoelectric human computer interface." Biomedical engineering online 14 (2015): 1-11.