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Case Study

Motor-Driven Switch Control Voluntary Opening Terminal Device for Precision Grip in Transradial Prosthesis: A Case Study

Tanmaya Kumar Pany[1], Prakash Sahoo[2], Nipul Swargiary[3], Nigar Parween[4], Dr Lalit Narayan [5]

[1]Demonstrator, NILD, Kolkata, India
[2]Demonstrator, NILD, Kolkata, India
[3]Internee (BPO), NILD, Kolkata, India
[4]Internee (BPO), NILD, Kolkata, India
[5]Director, NILD, Kolkata, India

Corresponding Author: Prakash Sahoo

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ABSTRACT

This study presents the design and development of a motor-driven switch control voluntary opening (VO) terminal device aimed at enhancing precision grip in transradial prosthesis users. Conventional VO prosthetic hands often lack the required grip strength and fine motor control, limiting functionality in daily activities. The proposed device integrates a motor-driven mechanism with switch-based control to improve grip efficiency and user adaptability. A case study was conducted to evaluate the device's performance in terms of grip force, control responsiveness, and ease of use. Preliminary results indicate improved precision grip and user satisfaction compared to conventional VO systems. This innovation has the potential to enhance prosthetic functionality and user independence.

Keywords: Transradial Prosthesis, Voluntary Opening, Motor-Driven Control, Precision Grip, Prosthetic Terminal Device.

INTRODUCTION

Major upper-extremity amputees account for only 8% of the 1.5 million individuals living with limb loss. The human hand is a powerful tool for sensing and operating in the environment, as well as a sophisticated means for physical and social interaction. It enables individuals to perform a wide range of movements, from power grips to precise manipulations, due to the large number of degrees of freedom and the crucial role played by thumb opposition. [1]

Technological advancements in any field are primarily driven by human needs and intellect. The human mind continuously seeks innovative solutions to improve functionality and convenience, leading to the evolution of various modern devices. This principle applies to prosthetic science as well, progressing from rudimentary materials such as iron and copper to the development of lightweight and highly functional prosthetic devices.[2]

Conventional upper extremity prostheses are primarily based on an exoskeletal system, which often makes them heavy and time-consuming to fabricate, particularly for transradial prostheses. Moreover, operating body-powered prosthetic devices requires considerable physical effort, contributing to the high rejection rates of such prostheses. [3-4] One of the critical challenges faced by individuals using voluntary opening (VO) prostheses is the limited grip strength and precision control, which restrict their ability to perform daily activities efficiently. [5-6]

This study presents the design and development of a motor-driven switch control voluntary opening (VO) terminal device aimed at enhancing precision grip in transradial prosthesis users. The proposed device incorporates a motor-driven mechanism with switch-based control to improve grip efficiency, responsiveness, and overall user adaptability. A case study was conducted to evaluate the device's performance in terms of grip force, control responsiveness, and ease of use. Preliminary results indicate improved precision grip and user satisfaction compared to conventional VO systems. This innovation has the potential to enhance prosthetic functionality and promote greater user independence.

Aim:

- To design and develop a motor-driven switch control voluntary opening (VO) terminal device to enhance precision grip in transradial prosthesis users.
- To improve the functionality and adaptability of VO prosthetic hands through motor-driven mechanisms and switch-based controls.
- To enhance user independence by improving grip efficiency and reducing the physical effort required for operation.

Objectives:

- To analyse the limitations of conventional voluntary opening prosthetic hands in terms of grip strength and precision control.
- To integrate motor-driven control and switch-based operation for better grip modulation and user responsiveness.
- To conduct a case study assessing grip force, control responsiveness, and ease of use.
- To evaluate user satisfaction and compare performance improvements against conventional VO prosthetic devices.

MATERIALS & METHODS

Materials

The proposed motor-driven switch control voluntary opening (VO) terminal device was developed using the following key components:

Power Source -

- A 12V battery supplied energy to the entire system.
- A switch (ON/OFF) was placed between the battery and the motor driver to control power flow.

Motor Driver (L298N) -

- The L298N motor driver controlled the direction and speed of the DC motor.
- The DC motor was connected to output pins 3 & 4 of the driver.

DC Motor & Motion Control -

- The DC motor drove a 3-jaw chuck, which mimicked finger opening and closing.
- The push button was wired to the motor driver's 5V output pin and input pins 3 & 4, enabling motion control.
- When pressed, the button activated the motor to open or close the fingers.

Functional Outcome

- The special wiring configuration between the motor driver, battery, and DC motor ensured that the prosthetic locks into position after reaching the desired grip.
- This locking mechanism enhanced stability and usability for the user.

METHODOLOGY

A case study approach was used to evaluate the effectiveness of the proposed device. The study involved a 45-year-old male with a right transradial amputation, who was previously using a body-powered prosthesis. The methodology followed these steps:

Subject Selection -

- The participant had prior experience using a body-powered prosthesis but reported issues such as bulkiness, weight discomfort, and difficulty in donning/doffing.
- The new motor-driven switch control device was fabricated and integrated into his prosthetic system.

Device Fabrication & Fitting -

- The electronic components, including the L298N motor driver, DC motor, and push button, were assembled within the prosthetic socket.
- The 3-jaw chuck system was tested for smooth and reliable finger opening and closing.
- The complete prosthetic device was fitted to the user and adjusted for optimal comfort and functionality.

User Satisfaction & Psychological Well-being -

- The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0) was used to measure user satisfaction before and after the intervention.
- Key factors such as ease of donning/doffing, weight distribution, comfort, and the ability to perform Activities of Daily Living (ADLs) were evaluated.
- Before the introduction of the new prosthesis, participants using a body-powered powered prosthesis had an average pre-test satisfaction score of 4.7, which fell under the category of "more or less satisfied." After using the prosthesis, the post-test score significantly improved to 8.7, reflecting a high level of satisfaction and moving closer to the "totally satisfied" category.

Through this methodology, the aim was to create a prosthesis that addressed the limitations of traditional body-powered devices, while providing an affordable, low-maintenance solution that could enhance the amputee's independence and overall quality of life.

RESULT

The evaluation of the motor-driven switch control voluntary opening (VO) terminal device demonstrated significant improvements in grip precision, control responsiveness, and user satisfaction. The following results were observed during the case study:

Grip Force and Precision -
The newly developed motor-driven VO terminal device exhibited enhanced grip efficiency compared to conventional body-powered prostheses. The user was able to achieve a controlled grip force suitable for precision-based tasks, such as grasping small objects and handling delicate items. The three-jaw chuck mechanism successfully mimicked natural finger movements, contributing to improved dexterity and functionality.

Control Responsiveness -
The push-button switch-based control mechanism allowed for smooth and reliable operation of the prosthetic hand. The user reported immediate responsiveness to input commands, facilitating a more intuitive and user-friendly experience. The locking mechanism effectively held objects in place without requiring continuous force, reducing muscle fatigue and effort required for operation.

User Satisfaction and Functional Outcomes -
The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0) was used to assess user satisfaction before and after the intervention. The following findings were recorded:

- Pre-test Satisfaction Score: 4.7 ("More or less satisfied")
- Post-test Satisfaction Score: 8.7 ("Highly satisfied")

The user reported improvements in comfort, ease of donning and doffing, and overall weight distribution. The enhanced prosthesis design allowed for greater independence in performing Activities of Daily Living (ADLs), including grasping utensils, handling household objects, and performing occupational tasks.

Comparative Performance Assessment

Parameter	Conventional VO Prosthesis	Motor-Driven VO Prosthesis
Grip Strength	Moderate	High
Control Responsiveness	Delayed	Immediate
Ease of Use	Moderate effort required	Minimal effort required
User Satisfaction (QUEST 2.0)	4.7	8.7
Fatigue Levels	High	Reduced

Qualitative User Feedback
The user expressed notable improvements in daily functionality, stating that the motor-driven system alleviated the physical strain associated with body-powered prostheses. The ability to maintain a steady grip without continuous exertion was highlighted as a major benefit. Additionally, the compact and lightweight design of the new device was perceived as an advantage over bulkier conventional models.

DISCUSSION

The results of this study highlight the significant advantages of incorporating a motor-driven switch control mechanism into voluntary opening (VO) prosthetic hands. Conventional VO prostheses often require continuous force exertion, which leads to fatigue and limited precision grip. The motor-driven system successfully addressed these limitations by enabling precise grip modulation and reducing the physical effort required for operation.

The improved grip efficiency observed in the case study aligns with previous research emphasizing the importance of adaptive and responsive control systems in prosthetics. The three-jaw chuck mechanism provided better dexterity, allowing the user to perform intricate tasks that were previously challenging with conventional VO prostheses. This suggests that integrating motor-driven components could bridge the gap between body-powered and myoelectric prostheses, offering a cost-effective and efficient alternative.

Furthermore, the substantial increase in user satisfaction, as indicated by QUEST 2.0 scores, underscores the practical benefits of this innovation. The enhanced ease of donning and doffing, combined with the lightweight and ergonomic design, contributed to an overall positive experience. These findings reinforce the necessity of user-centered design approaches in prosthetic development.

Despite these promising outcomes, certain limitations must be acknowledged. The study was based on a single case, limiting the generalizability of the findings. Additionally, long-term durability and battery efficiency were not extensively evaluated. Future research should involve a larger sample size and longitudinal studies to assess the long-term impact and reliability of motor-driven VO prosthetic devices.

CONCLUSION

The findings of this study indicate that the motor-driven switch control VO terminal device significantly enhances grip efficiency, user adaptability, and overall satisfaction. The improved control responsiveness and reduced effort required for operation contribute to a more user-friendly and functional prosthetic solution.

This innovation holds promise for further advancements in prosthetic technology, offering increased independence and improved quality of life for transradial amputees. Future work should focus on optimizing power consumption, refining control mechanisms, and expanding clinical trials to validate the broader applicability of this approach in prosthetic rehabilitation.

Declaration by Authors

Ethical Approval: Not Applicable

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