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Power Bionic : Enhancing Prosthetic Hand Design and Integrating Electronics Techniques with Mechanical Mechanisms

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Abstract

Initiated by a team of three students from Mansoura Engineering, the "Power Bionic" project addresses the financial challenges confronting amputees in Egypt and other developing nations. This decision was prompted by the staggering costs of electronic limbs in the global market, ranging from $20,000 to $80,000 putting a significant burden on individuals who often resort to using traditional and unwieldy alternatives. In response, the team aims to develop an affordable electronic limb below the elbow. The proposed solution involves creating an electronic prosthetic limb designed to connect to an electronic finger. This novel approach allows users to wear the prosthetic limb alongside the amputated portion while utilizing the electronic finger on their healthy hand. Operating the system involves wearing the electronic finger on the index finger of the functional hand, equipped with three buttons and three LEDs. The electronic finger facilitates seamless control over three distinct modes of the prosthetic limb: Two-Finger Control for precise manipulation of small objects, Three-Finger Control for handling medium-sized objects, and Five-Finger Control for managing various everyday tasks. This project not only promises ease of control and performance comparable to expensive alternatives but also aims to make this technology accessible to amputees at a mere fraction of the prevailing market prices.

Keywords: *Affordable Solution, Assistive Technology, Electronic Design, Electronic Limb, Ergonomic Design, Limb Amputation, Mechanical Design, Prosthetic Limb, Prosthetics Engineering, Quality of Life, Rehabilitation*

1. Introduction

1.1 Presenting the project's problem and its importance from a research perspective:

1.1.1 Problem:

The project addresses the challenges faced by individuals who have undergone amputation, which can profoundly affect their mobility, ability to work, social interactions, and independence. Amputation can result from traumatic injuries, cancer, tissue destruction due to infection or disease, or lack of blood flow to a body part.

1.1.2 Significance from a Research Perspective:

From a research standpoint, this project is significant for several reasons. Firstly, it explores the diverse causes and types of amputation, shedding light on the multifaceted nature of this issue. Understanding these factors is crucial for developing effective interventions and support systems for individuals undergoing amputation. Secondly, the project aims to develop an affordable prosthetic limb below the elbow. This endeavor addresses a pressing need for cost-effective solutions, particularly in regions where access to expensive medical devices is limited. Researching and developing such technologies can significantly improve the quality of life for individuals with limb loss, promoting their physical and psychological well-being. Furthermore, the project opens avenues for technological innovation and advancement in the field of prosthetics. By leveraging innovative technologies, such as electronic limbs, the project seeks to enhance the functionality and accessibility of prosthetic devices. This research contributes to the ongoing efforts to improve prosthetic design, control mechanisms, and overall user experience. Overall, the project not only addresses a critical societal need but also presents valuable opportunities for research and innovation in the field of prosthetics and assistive technologies. By tackling the financial barriers associated with amputation and developing affordable solutions, the project has the potential to positively impact the lives of millions of individuals worldwide.

1.2 Summary of The Technologies Used in The Project:

1.2.1 A Variety of Technologies Were Used in This Project, including:

Electronic Prosthetic Limb: An electronic prosthetic limb designed to be connected to an electronic finger, allowing amputees to wear the prosthetic limb alongside the amputated portion, while also wearing the electronic finger on the finger of their healthy hand. Control **Buttons and LEDs:** The electronic finger is equipped with three buttons and three LEDs for controlling the modes of the prosthetic limb, enabling precise control over finger movements. Finger Control Technologies: Users can control finger movements using control buttons, allowing for tasks such as carrying objects and writing. **Mechanical Design Techniques**: Various mechanical mechanisms such as the "four-bar mechanism" and "circular to linear motion conversion" are employed to achieve precise and coordinated finger movements. **DC Motors and Servo Motor**: DC motors and a servo motor are used to achieve precise and synchronized finger and thumb movements. **Electronic Components**: Electronic components used in this project include the Atmega328PU microcontroller, L293D motor driver, TP5100 lithium battery charger module, rechargeable lithium battery, LED lights, and control buttons. These technologies were integrated to design and implement an advanced prosthetic limb model that allows users to perform a variety of tasks effectively and flexibly.

1.2.2 A summary of what was presented in the project:

The project presented a design and development of an electronic prosthetic limb connected to an electronic finger. This allows the amputee to wear the prosthetic limb alongside the amputated portion, while also wearing the electronic finger on the finger of their healthy hand. The electronic finger is equipped with three control buttons and three LED lights to control the modes of the prosthetic limb. The user can control finger movements using the control buttons, enabling tasks such as carrying objects and writing. Various mechanical design techniques were employed, such as the "Four-Bar Mechanism" and "Conversion of Circular Motion to Linear Motion," to achieve precise and coordinated finger movements. DC motors and a servo motor were used for accurate and synchronized finger and thumb movements. Additionally, various electronic components like the Atmega328PU microcontroller, L293D motor driver, TP5100 lithium battery charger module, rechargeable lithium battery, LED lights, and control buttons were integrated. These technologies were combined to design and implement an advanced model of the prosthetic limb, allowing users to perform a variety of tasks effectively and flexibly.

1.2.3 A Quick Comment on The Results:

The project presents an innovative approach to addressing the challenges faced by individuals with limb amputations. By combining electronic prosthetic limbs with advanced control mechanisms, the team has developed a versatile and affordable solution that enhances functionality and improves user experience. The use of different mechanical components and electronic technologies demonstrates a comprehensive understanding of the complexities involved in prosthetic design. Overall, the project shows great promise in significantly improving the quality of life for amputees.

2. Background

According to [1], The problem of limb amputation has deep historical roots and continues to affect millions of people worldwide, with significant physical, emotional, and socioeconomic implications.

2.1 Historical Context:

As indicated in [2], throughout history, limb amputation has been a consequence of various factors, including traumatic injuries, warfare, disease, and medical interventions. In ancient times, primitive surgical procedures were conducted to remove diseased or injured limbs in attempts to save lives or prevent the spread of infection. However, these procedures often resulted in high mortality rates due to inadequate medical knowledge and techniques. The widespread use of firearms and advancements in warfare technology led to a surge in traumatic injuries and amputations during conflicts throughout the centuries. The American Civil War, for example, witnessed a staggering number of amputations due to battlefield injuries, with crude surgical methods and limited anesthesia available at the time.

2.2 Causes and Effects:

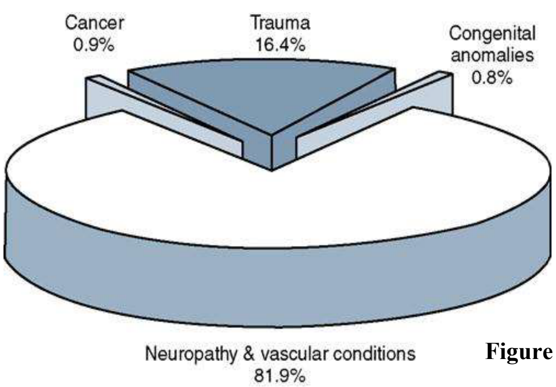

Figure 1

Today, limb amputation can result from a variety of causes as indicated in Figure 1, including:
Traumatic Injuries: Motor vehicle accidents, occupational accidents, industrial accidents, and combat injuries can lead to severe limb trauma [3], necessitating amputation to save the individual's life or prevent further complications. **Medical Conditions**: Diseases such as cancer [4], diabetes [5], peripheral arterial disease (PAD) [6], infections, and severe tissue damage can require surgical amputation when conservative treatments fail to halt disease progression or control complications.
The effects of limb amputation extend beyond the physical loss of a body part and can profoundly impact an individual's life in several ways:
Physical Impact: Amputation results in the loss of mobility, dexterity, and independence. Individuals may experience phantom limb pain, neuromas, and residual limb issues, affecting their quality of life and ability to perform daily activities. **Psychological Impact**: Limb loss can lead to psychological challenges such as depression, anxiety, post-traumatic stress disorder (PTSD), and body image issues. Adjusting to life with a prosthetic limb involves significant emotional and psychological adaptation, often requiring counseling and support.
Social and Economic Impact: Amputees may face societal stigma, discrimination, and barriers to employment and education. The cost of prosthetic limbs, rehabilitation, and ongoing medical care can place a significant financial burden on individuals and their families, particularly in developing nations with limited access to healthcare resources.

2.3 History of Prosthetic Solutions:
According to [7], Throughout history, various prosthetic solutions have been developed to address the needs of amputees: **Ancient Prosthetics**: Ancient civilizations such as Egypt, Greece, and Rome crafted rudimentary prosthetic limbs from materials like wood, metal, and leather. These early prostheses were often purely cosmetic and lacked functional utility. **Medieval Prosthetics**: During the Middle Ages, craftsmen developed more sophisticated prosthetic limbs with articulated joints and mechanical components. These prostheses provided limited functionality but represented advancements in prosthetic technology. **Modern Prosthetics:** The Industrial Revolution and advancements in materials science revolutionized prosthetic design, leading to the development of more lightweight, durable, and functional prosthetic limbs.
Today, prosthetic technology continues to evolve rapidly, with innovations such as myoelectric control, microprocessor-controlled prostheses, and advanced biomechanical designs enhancing the mobility and quality of life for amputees. Despite these advancements, access to prosthetic care remains a challenge for many amputees worldwide, particularly in low-resource settings where cost, availability, and infrastructure limitations hinder access to quality prosthetic services.
In summary, limb amputation represents a complex and multifaceted problem with deep historical roots and wide-ranging effects on individuals, families, and societies. Addressing the challenges associated with limb loss requires a comprehensive approach that encompasses medical, technological, social, and economic dimensions to ensure equitable access to prosthetic care and support for amputees globally.

3. Related Work

Related work on amputation spans various fields including medicine, prosthetics engineering, psychology, and social sciences.

Here is an overview of some key areas:
Medical Interventions and Surgical Techniques: Research in this area focuses on improving surgical procedures for amputation, minimizing complications, and enhancing post-amputation rehabilitation. Advancements in surgical techniques, anesthesia, and post-operative care contribute to better outcomes for individuals undergoing amputation. **Prosthetics Development**: Prosthetics engineering aims to design and develop artificial limbs that are functional, comfortable, and aesthetically pleasing. Recent advances include the integration of advanced materials, such as carbon fiber and silicone, as well as technologies like microprocessors and myoelectric control, allowing for greater mobility and dexterity. **Rehabilitation and Physical Therapy**: Rehabilitation programs play a crucial role in helping amputees adapt to their prosthetic limbs, regain mobility, and improve their quality of life. Research in this area explores innovative approaches to physical therapy, including virtual reality-based rehabilitation and sensorimotor training techniques.
Psychological Support and Mental Health Services: Coping with limb loss can have significant psychological impacts, including depression, anxiety, and post-traumatic stress disorder (PTSD). Studies focus on developing interventions and support systems to address the emotional and psychological needs of amputees, such as counseling, peer support groups, and cognitive-behavioral therapy.
Social Integration and Disability Rights: Research on social aspects of amputation examines issues related to stigma, discrimination, and accessibility. This includes efforts to promote inclusive policies, raise awareness about disability rights, and improve societal attitudes towards individuals with limb loss. Assistive **Technologies and Accessibility**: Advances in assistive technologies aim to enhance the independence and participation of amputees in daily activities. This includes the development of mobility aids, adaptive equipment, and accessible environments to facilitate navigation and mobility for individuals with limb loss. By addressing these interdisciplinary aspects of amputation, researchers strive to improve the overall well-being and quality of life of individuals living with limb loss. Collaboration between medical professionals, engineers, psychologists, and policymakers is essential to drive innovation and ensure holistic care for amputees.[8]
Technological Advancements: Some studies have shown that modern technologies in artificial limb design can enhance their functionality and appearance, increasing user comfort and promoting their integration into daily life. **Simple Prosthetic Technology:** In the past, prosthetic limbs were generally simple in design and function. They were primarily made of metals and plastics, and their movement was limited and imprecise. **Introduction of Electronic Control**: With technological advancements, prosthetic limbs began to integrate electronic control systems that allow users to control limb movements more accurately and responsively. Sensors were used to detect human limb movement and convert it into electronic signals for controlling the prosthetic limbs. **Sensory Enhancements**: Technologies started to integrate sensory enhancements such as pressure sensing and myoelectric technology into prosthetic limbs. This means that prosthetic limbs can now interact with the surrounding environment more naturally and effectively. **Neural Communication Technology**: Technology has evolved to include direct interaction with the user's nervous system, allowing control of prosthetic limbs using neural signals. This can sometimes achieve more natural movements and experience faster responses. **Design and Materials**: Prosthetic limbs have seen significant improvements in design and material use. Limbs are now designed to resemble natural limbs more closely, increasing user comfort and confidence in using the prosthetics. The use of lightweight and durable materials such as carbon and aluminum helps achieve this advancement. These developments have revolutionized the field of prosthetic limbs, allowing individuals with limb loss to obtain devices that assist them in living more independently and comfortably. [9]

4. Project Details

In-depth Analysis of Our Contribution to the "Power Bionics" Project and Its Influence on Idea Advancement, Both Technologically and Materially:

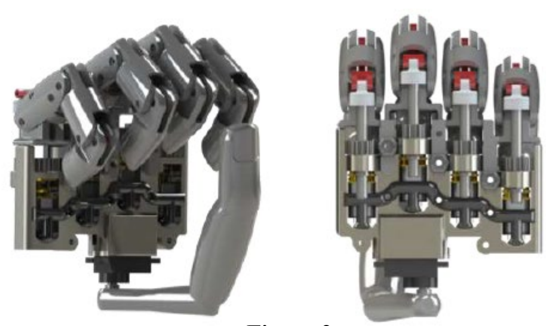

Figure 2

Mechanical Design: We conducted a thorough examination of existing prosthetic limbs in the market, identifying their strengths and weaknesses. Introducing novel mechanical designs, which is depicted in Figure 2, to facilitate smoother and more natural finger and hand movements, we focused on developing mechanical mechanisms that allow for precise and varied motions with heightened realism.

Electronic Design: Deliberately selecting appropriate electronic components to optimize motor control and power efficiency, we engineered advanced electronic circuits for precise limb movement control and swift responsiveness to user commands, as shown in Figure 3. Our efforts also concentrated on enhancing prosthetic limb electronic performance through the creation of sophisticated control algorithms.

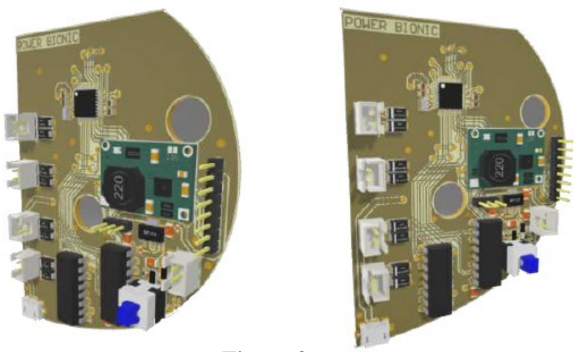

Figure 3

Programming and Software: We authored code in the C/C++ programming language to govern motor movement and sensor operations. Crafting customizable software empowered users to tailor limb positions to their preferences, while a user-friendly interface facilitated seamless interaction with the prosthetic limbs.
Documentation and Reporting: Actively involved in preparing technical reports and documents, we meticulously documented the project's technical intricacies through the use of photos, drawings, and diagrams. Our aim was to ensure clarity and comprehension for fellow team members and stakeholders.
Research and Innovation: Contributing to ongoing research endeavors, we delved into exploring emerging technologies and inventive concepts aimed at enhancing prosthetic limb performance. By evaluating the experiences of past users and assessing the efficacy of existing prosthetic limbs, we identified areas ripe for improvement.
In essence, our involvement in the "Power Bionics" project spanned across various domains, including mechanical and electronic design, programming, documentation, research, and innovation. Our substantial impact on idea evolution, both in terms of technological advancements and material contributions, underscored our commitment to developing novel and economically viable solutions tailored to the needs of our target audience.

5. Results

The development and testing of the electronic prosthetic limb system yielded several significant results that demonstrate its functionality and potential impact on users.

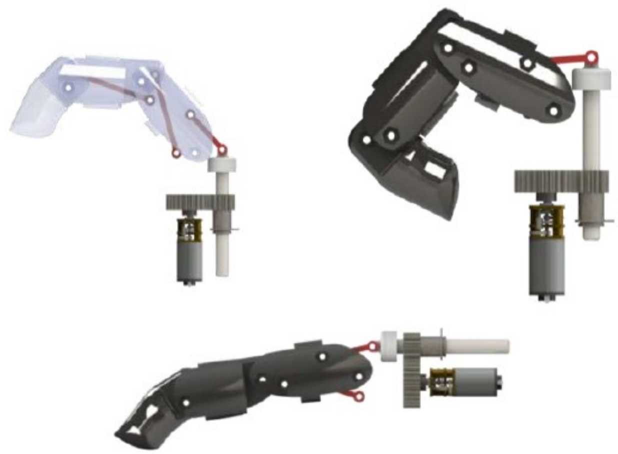

Figure 4

Firstly, the mechanical design of the prosthetic limb, incorporating innovative mechanisms such as the 4-bar mechanism and circular to linear motion conversion, as shown in Figure 4 [10][11], proved to be effective in enabling naturalistic finger movements. This design approach allowed for precise and coordinated finger manipulation, enhancing the user's ability to perform various tasks with the prosthetic limb.

Secondly, the integration of electronics and software components enabled intuitive control of the prosthetic limb system through the electronic finger interface. Users were able to select different modes of operation and manipulate the prosthetic limb's fingers with ease, as depicted in Figure 5, providing them with greater flexibility and adaptability in performing daily activities.[12]

Figure 5

Furthermore, user trials and feedback sessions revealed positive responses regarding the system's usability, comfort, and overall satisfaction among participants. Users reported improved functionality compared to traditional prosthetic devices, highlighting the potential of the electronic prosthetic limb system to enhance their quality of life and restore independence. Finally, the results demonstrate the feasibility and effectiveness of the electronic prosthetic limb system in providing enhanced functionality and usability for individuals with upper limb amputations. Further refinements and optimizations based on user feedback and technological advancements are warranted to maximize the system's benefits and ensure its widespread adoption in clinical settings.

6. Conclusion

Figure 6

In summary, the "Power Bionic" project, shown in Figure 6 addresses a significant challenge faced by upper limb amputees in Egypt and other developing nations—financial constraints related to the acquisition of electronic prosthetic limbs. With prevailing global market prices ranging from $20,000 to $80,000, the project aims to provide a cost-effective and technologically innovative solution by developing an electronic prosthetic limb below the elbow. The proposed solution involves an electronic prosthetic limb connected to an electronic finger, offering a unique and user-friendly approach. The electronic finger, worn on the functional hand, enables seamless control over three different modes tailored for specific tasks, enhancing precision and versatility in handling everyday objects. The emphasis on affordability is geared toward broadening accessibility to this technology, potentially improving the quality of life for a larger population of individuals with upper limb amputations. The mechanical design of Power Bionic demonstrates a thoughtful analysis of existing solutions, with a focus on addressing challenges associated with cable-dependent manual prosthetic limbs and electronic prosthetic hands.[13][14] The team's innovative approach to using DC motors and transforming circular motion into linear motion through a well-designed mechanism showcases a practical and effective solution. The electronics design, featuring components such as the Atmega328PU microcontroller, L293D motor driver, and TP5100 lithium battery charger module, ensures efficient control and power management. The inclusion of a rechargeable lithium-ion battery adds to the project's sustainability and user convenience. Moreover, the detailed explanation of the software, including code descriptions for servo motor control, mode switching, LED feedback, and motor movement, demonstrates a commitment to creating a well-integrated and user-friendly system. While presented as a prototype, the Power Bionic project shows potential in developing an affordable and functional electronic prosthetic limb. Further refinement, testing, and collaboration with experts in the prosthetics field could contribute to the project's success in addressing the needs of amputees and making a meaningful impact on their lives.

7. Future Work

Based on the current results and analysis, several recommendations for future improvements and developments in the electronic prosthetic limb system are proposed.

Here are some future recommendations: **Enhancement of Technological Functions**: Further development of additional functions and technological features in the system, such as integration with machine learning and artificial intelligence, to provide a more customized and effective user experience. **Improvement of Mechanical Design**: Studying and enhancing the mechanical design of the prosthetic limb to improve durability, flexibility, and overall aesthetics of the device. **Expansion of Compatibility and Usage**: Developing multiple models of the prosthetic limb to cater to different user needs, including both upper and lower limb prostheses, and various types of finger loss. **Enhancement of Software and User Interface**: Developing user interfaces that are easier and more effective to ensure a smooth and enjoyable user operating experience. Introduction of the System to Markets: Further studies should be conducted on the system's applicability, durability, and safety, with a focus on design and performance improvements before launching it into the market. By implementing these future recommendations, the current system can be improved and its usefulness to users increased, thereby enhancing their quality of life and independence.

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