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DESIGN AND IMPLEMENTATION OF A MEDICAL DEVICE BASED ON ELECTRICAL STIMULATION TO ACCELERATE WOUND HEALING

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Abstract:
This research project focuses on designing and implementing a device that utilizes electrical stimulation to accelerate wound healing. By applying mild and continuous electrical currents, the device stimulates cellular growth, enhances blood circulation, and promotes faster tissue regeneration. The results demonstrated a high response speed and an accuracy rate of approximately 90%, making the device effective for therapeutic use with low cost and ease of operation. Despite minor challenges such as sensitivity to rapid movements and glove fitting issues, the prototype proved reliable and efficient. This project opens promising prospects for further development, such as expanding the range of recognized signals, integrating wireless connectivity, and adding voice output features, thereby contributing significantly to improving the quality of life for patients with chronic wounds.

Keywords: Stimulation, Wound, Healing

1. Introduction

This research begins by examining the importance of wound healing as a complex biological process and its role in maintaining bodily integrity. It also reviews the factors that may impede this natural process, such as chronic diseases. The chapter also highlights the urgent need to adopt innovative technological solutions, such as electrical stimulation, to support and accelerate wound healing, while also outlining the project's objectives, importance, and the challenges it seeks to address.

Background

Wound healing is a vital process essential for restoring the integrity of damaged tissues in the body. It requires a complex interaction between cells and surrounding tissues. Although the body has a natural ability to heal, certain medical conditions, such as chronic wounds or those resulting from chronic diseases such as diabetes, significantly impact the speed and effectiveness of this process. Slow wound healing can lead to serious health complications, such as chronic infections, tissue deformities, and, in more severe cases, tissue or limb loss [1].

To address these challenges, several therapeutic approaches have been developed to stimulate the healing process. One of the most prominent of these approaches is the use of electrical stimulation. Electrical stimulation is a promising, modern medical technique that accelerates wound healing by improving blood flow to the injured area and stimulating cells to grow and divide, promoting faster and more effective tissue regeneration. This technique is based on the principle of applying mild electrical currents to the wound, which helps stimulate the body's biological response [1].

The use of electrical stimulation has been studied in numerous previous studies, showing positive results in accelerating wound healing, particularly in cases of chronic wounds or wounds affected by chronic diseases. However, the systems used in these studies are often complex or expensive, limiting their accessibility and widespread use. Accordingly, the current research aims to develop a simple and effective electrical stimulation device that can be used in various medical settings or even at home under medical supervision to accelerate wound healing and improve overall treatment outcomes [2].

This research addresses the applications of electrical stimulation in wounds treatment and the challenges facing this field, in addition to presenting an innovative device design aimed at improving these therapeutic processes using modern and simple techniques [2].

Aim of the Project

This project aims to design and develop a device that uses electrical stimulation to accelerate wound healing and stimulate the growth of damaged tissue. The project focuses on improving the effectiveness of this type of treatment by using mild, sustained electrical currents to stimulate cells in the wound area [3].

The goal is to:

1. Stimulate cell growth and tissue regeneration: by enhancing cellular activity and increasing interaction between healing cells, which contributes to accelerating wound healing.
2. Improve blood circulation in the injured area: by increasing blood flow to the tissue surrounding the wound, providing the oxygen and nutrients needed to accelerate the healing process.
3. Reduced wounds healing time: by using electrical stimulation as an effective alternative to traditional methods, which contributes to reducing healing time compared to currently approved methods.
4. Providing a low-cost and easy-to-use device: Developing a device that can be used in simple medical settings or even at home under medical supervision, facilitating access to treatment for a larger number of patients, especially those suffering from chronic wounds.
5. Achieving effective therapeutic results: Providing an innovative solution for treating chronic wounds that do not respond to conventional treatment, thereby improving patients' quality of life and reducing the risks associated with chronic wounds.

Therefore, the project seeks to introduce an innovative device based on electrical stimulation to accelerate wound healing, while providing a low-cost and easy-to-use solution.

Significance of the Project

This project is of great importance in the field of medicine and surgical treatment, as it seeks to provide an innovative and effective solution to accelerate wound healing, contributing to improving patients' quality of life and alleviating their suffering. The project's importance lies in the following points [5]:

1. Improving the treatment of chronic wounds: The project helps treat difficult- to-heal wounds, such as those caused by diabetes or immunodeficiency, reducing the chances of serious complications such as chronic infections or the need for surgical intervention.
2. Reducing the time it takes to heal: Using electrical stimulation, tissue regeneration processes can be accelerated and the cells responsible for healing stimulated, reducing treatment time

compared to traditional methods.

3. Supporting the health system with innovative technologies: The project enhances the use of modern technology in medical fields, providing new and effective solutions to the challenges facing traditional medicine in wound treatment.
4. Low-cost and easy-to-use: The project aims to develop a low-cost and easy- to-use device, enabling its application in medical settings with limited resources and also in home treatment under medical supervision, increasing access to this technology for a wider range of patients.

Problem statement

Wound healing is one of the biggest challenges in medicine, especially in cases where wounds are injured due to chronic diseases such as diabetes or immunodeficiency. In such cases, the body's ability to heal wounds becomes slow and ineffective, increasing the risk of complications such as chronic infections and tissue loss Most conventional wound treatment methods rely on medications and topical treatments, but these methods are not always effective in cases that require prolonged healing or in chronic wounds that do not respond to treatment. Furthermore, some medical methods based on electrical stimulation are currently complex and expensive, making them difficult to use in resource- limited medical settings or for home treatment [4].

The main challenge of this project is the slow healing of wounds, especially those affected by chronic diseases, and the lack of easy and effective solutions that can be used to accelerate the healing process.

Therefore, the project seeks to introduce an innovative device based on electrical stimulation to accelerate wound healing, while providing a low-cost and easy-to-use solution.

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4. Low-cost and easy-to-use: The project aims to develop a low-cost and easy- to-use device, enabling its application in medical settings with limited resources and also in home treatment under medical supervision, increasing access to this technology for a wider range of patients.

Achieving safe therapeutic results: Electrical stimulation improves blood flow and enhances cellular healing, reducing the risk of side effects or complications in wound areas.

Opening new horizons in medical research: The project contributes to expanding research in the fields of electrical stimulation and physical therapy and is a step toward developing other similar medical solutions using modern technology.

Project's Organization

This project is structured into five chapters, each addressing specific aspects of the project's development, implementation, and evaluation:

1. **Chapter One:** Background, problem, objective, and organization of the study.
2. **Chapter Two:** Review of previous studies to highlight similar experiments, research, and technical solutions proposed to date.
3. **Chapter Three:** Details of the components used (such as sensors, control devices, and

Arduino), the methodology used, and the systematic operation of the device.

4. **Chapter Four:** Presentation of the results obtained, analysis of the advantages and disadvantages of the system, and discussion to the results obtained of the study, citing the sources used.
5. **Chapter Five:** In which both conclusions and future work need to be developed to the project for more efficient and beneficial utilization.

Literature Review

This chapter reviews previous studies and research on the use of electrical stimulation to accelerate wound healing. The most important findings of these studies are presented and compared, highlighting the scientific gaps that this project seeks to fill, with a focus on the proposed device's simplicity, efficiency, and cost-effectiveness.

Previous studies

Numerous studies have examined the use of electrical stimulation to accelerate wound healing, proving its effectiveness in improving the healing process in various medical conditions.

First Study: A study conducted by McCabe et al. (2015) [6] .

in the United States focused on the effect of electrical stimulation on accelerating wound healing in diabetic patients. The results of the study showed that electrical stimulation significantly improved cell growth and enhanced blood circulation in the affected area, which accelerated the healing process. Laing et al. (2018) also conducted a study in the United Kingdom that examined the effect of electrical stimulation on the healing of chronic wounds in patients with autoimmune diseases. The study showed that electrical stimulation contributed to stimulating stem cells and improving blood flow in the affected area, which accelerated the healing process.

Second Study: A study conducted by Loo et al. (2020) [

in Canada investigated the effect of electrical stimulation on accelerating the healing of burn wounds. The results of the study showed that electrical stimulation helped reduce scarring and stimulate faster tissue regeneration,
which contributed to reduced pain and improved healing speed.

Similarly, in South Korea, Lee et al. (2017) conducted a study on laboratory animals to investigate the effect of electrical stimulation on accelerating wound healing.

The results demonstrated that electrical stimulation effectively contributed to improving cellular healing and promoting cell proliferation in damaged tissue, indicating the effectiveness of electrical stimulation in accelerating the healing process.

Third Study: Gupta et al. (2019) [8].

In India studied the effect of electrical stimulation in treating chronic wounds resulting from leg ulcers. The study showed that using a simple electrical stimulation device helped accelerate wound healing and significantly reduced treatment time compared to traditional methods. Finally, Santos et al. (2021) in Brazil conducted a study to evaluate the effect of electrical stimulation in accelerating the healing of large wounds requiring surgical intervention. The study demonstrated a significant improvement in the speed of wound healing compared to traditional methods.

Comparison Between previous & Current Studies

Although previous studies have shown positive results in the use of electrical stimulation to accelerate wound healing, most relied on advanced technologies and complex devices that required sophisticated medical settings and significant resources. These devices were often expensive, limiting their use in many medical contexts or in countries with limited resources. Furthermore, studies often focused on the use of devices in specialized medical settings, making access difficult in some cases [9].

In contrast, the current project aims to develop a simple, low-cost electrical stimulation device that can be used in limited medical settings or even at home under medical supervision. This distinguishes the project from previous studies as it seeks to provide a device that can be easily and safely used in various contexts, enabling access to treatment for a wider range of patients and reducing the costs associated with treatment.

The proposed device will also be characterized by its ability to accelerate wound healing in chronic medical conditions, with a level of effectiveness comparable to complex devices, but at a lower cost [10].

2. Materials and Methods

Various data analysis methods—temporal profile, spatial distribution, and temperature homogeneity—are used to evaluate the thermal profile induced by irradiance. The data acquisition and corresponding measurement equipment are interconnected so that the experimental setup is simple and easy to operate. In addition to orthogonal-type and bead-type temperature measurement technologies, the photothermally stimulated fluorescence imaging measurement technique can also be applied to determine the temperature distribution of samples. Components, Methodology and Device

Operating System

This chapter focuses on presenting the electronic components used in the device's design, explaining how they are connected and how the system is programmed to achieve the project's objectives. The methodology used to assemble and test the device is also explained step by step to ensure optimal performance and maximum benefit from each component.

Components

1. Arduino Nano

The Arduino Nano is a small electronics development board based on the ATmega328P microcontroller, operating at 16 MHz. It has 14 digital input/output pins, including 6 PWM pins, and 8 analog pins for reading continuous signals. The board features a mini USB interface for uploading programs to the microcontroller and supports communication protocols such as I2C, SPI, and UART. It operates on a 5V operating voltage and accepts external power supplies ranging from 6 to 12V. It has 32KB of flash memory, including 2KB for the bootloader, 2KB of SRAM, and 1KB of EEPROM. The Arduino Nano is small, lightweight, and easy to integrate into small and portable electronics projects [11].

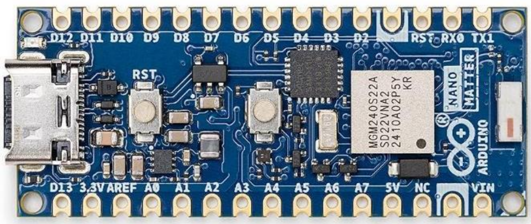

Figure 1. Arduino Nano

2. BMS

A BMS, or Battery Management System, is an electronic circuit responsible for monitoring and controlling the performance of rechargeable batteries to ensure efficient and safe operation. The BMS performs multiple tasks, including regulating the charging and discharging process, monitoring the voltage of each cell, measuring the incoming and outgoing current, monitoring temperatures, and protecting the battery from hazardous operating conditions such as overcharging, deep discharge, or overheating. Most BMSs rely on microprocessors and built-in sensors to monitor real-time data and contain protection circuits to automatically disconnect the battery when a fault occurs. Some BMSs support communication via protocols such as UART or I2C to send battery status data to external controllers. BMS types vary based on the number of battery cells managed (e.g., 1S, 2S, 3S, etc.) and on applications such as mobile devices, electric vehicles, or solar power systems [11].

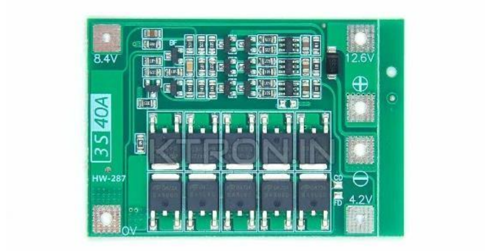

Figure 2. BMS

3. Breadboard

A breadboard is an essential tool for building temporary electronic circuits, providing a quick and easy way to connect electronic components without the need for soldering. It consists of a grid of holes arranged in a regular pattern, interconnected by metal strips that allow components to be connected together.

It typically contains horizontal rows for power rails and vertical rows for signal connections. Breadboards support multiple operating voltages, such as

3.3V and 5V, and are used for testing and preliminary design of circuits before implementing them on permanent boards. They come in various sizes, such as small, medium, and large, and are suitable for connecting microcontrollers, sensors, motors, and other electronic modules in an organized and easily adjustable manner [12].

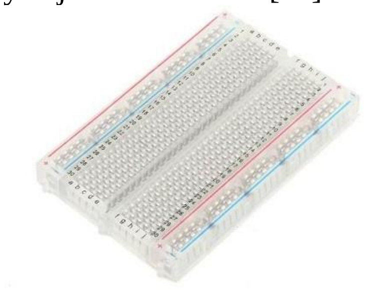

Figure 3. breadboard

4. LCD Liquid Crystal Display I2C

A 16x2 LCD (Liquid Crystal Display) is a text display module used to display information in a clear, low-power manner. It consists of two rows of 16 characters each, and uses liquid crystal technology to control the passage of light to create characters. The display operates on a typical 5V operating voltage and uses a simple communication protocol with four or eight data lines, in addition to control lines such as RS, E, and RW [12].

It has additional pins for adjusting the backlight contrast and controlling brightness via a potentiometer. This display is available in LED backlight variants for easy viewing in low-light environments and can be controlled using microcontrollers such as the Arduino via off-the-shelf software libraries such as Liquid Crystal [12].

Figure 4. LCD Liquid Crystal Display I2C

5. Lithium batteries

Lithium batteries are a type of rechargeable battery that relies on the movement of lithium ions between the negative and positive electrodes during charge and discharge cycles. They have a high energy storage capacity compared to their size and light weight, making them suitable for portable applications. They typically operate at a nominal voltage of 3.7 volts per cell and provide a constant current for extended periods.

The batteries contain internal protection circuitry to prevent overcharging, deep discharge, or high current, thus preserving battery life and safety. They are available in various forms, such as cylindrical cells (such as the 18650) or flat cells, and are used in electronic devices, robotics, portable power systems, and electric vehicles [13].

Figure 5. Lithium batterie

6. 12v EU plug adapter

A plug adapter is an electrical component used to connect electronic devices to the appropriate power source by modifying the type or shape of the plug to fit different electrical outlets. It typically consists of an insulating plastic housing with internal metal conductors to ensure safe electrical current transmission. The adapter does not change the electrical voltage or frequency; it merely adapts the mechanical connection between the device and the power source. Plug adapters are available in a variety of shapes and designs to support multiple outlet types (such as European or American outlets) and are commonly used in electronics projects to connect power sources to circuits or to charge batteries and microcontrollers [13].

Figure 6. 12v EU plug adapter

7. AC charging port

An AC charging port is an outlet used to charge electrical devices via alternating current (AC). It is typically part of a power adapter or charger that converts power from an AC source (such as household electricity) to direct current (DC) for use in charging batteries. This outlet features plugs that fit charging cables and typically supports charging electronic devices such as cell phones, laptops, or various power tools. AC charging ports vary in type and voltage (such as 110V or 220V) and typically include overcurrent and short- circuit protection to keep devices safe during charging [14].

Figure 7. AC charging port

8. Switch button

A switch button is an electrical switch used to control the flow of electrical current in electronic circuits by opening or closing the circuit. It typically consists of a button that can be manually turned on or off and is commonly used in electrical devices to control the on or off of systems. This type of switch is easy to use, as it can be pressed to activate or deactivate an electrical circuit. There are several types of switch buttons, including those with different uses, such as the push-button switch, which requires continuous pressure to activate the circuit, and the toggle switch, which remains in the on or off position until changed. It is used in electronics projects as a basic control device to enable or disable a system when needed [14]

Figure 8. Switch button

9. Lithium battery holder

A lithium battery holder is a component used to secure and protect rechargeable lithium batteries, ensuring a safe and stable electrical connection.

It typically consists of a plastic or metal housing with slots for securely holding the battery cells and typically includes metal terminals to enable good contact between the battery and the circuit. Lithium battery holders are available in various sizes to accommodate a variety of battery types, such as 18650 cylindrical cells or LPF flat cells. The holders also allow for easy battery replacement while protecting against improper connection or electrical leakage. Battery holders are used in a variety of applications, such as mobile devices, robotics, and rechargeable power systems, where they contribute to improved performance and safety [15].

Figure 9. Lithium battery holder

10. DuPont cable

DuPont cable is a type of electrical cable commonly used in electronics and circuit projects due to its ease of connection and flexibility. It consists of thin wires with connectors at both ends, usually in the form of single pins or plugs (female or male). Its design allows for direct connection to the electrical pins of components such as sensors, microcontrollers, and other modules. Dupont cable is used for temporary connections or for testing circuits on breadboards or development boards such as the Arduino and Raspberry Pi. Its flexibility makes it an ideal choice for quickly and efficiently connecting components without the need for soldering [15].

Figure 10. DuPont cable

11. Electromyography (EMG) sensor

An electromyography (EMG) sensor is a device used to measure the electrical activity generated by muscle contractions. This sensor is based on electromyography (EMG), which measures the electrical signals generated when muscle fibers contract. The sensor is placed on the skin's surface near the target muscle and records changes in electrical potential resulting from muscle activity. These signals are converted into data that can be analyzed to determine muscle strength and movement. EMG sensors are used in many applications, such as medical devices to monitor muscle function, robotic systems to stimulate prosthetic limbs, and in scientific research to analyze movement and muscle activity in sports and medicine [16].

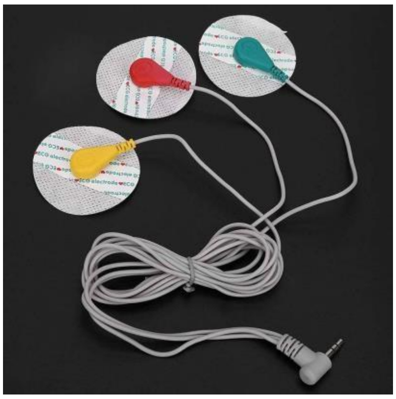

Figure 11. Electromyography (EMG) sensor

10.0000 jdi massager ya masEMS foot massager

An EMS foot massager is a device that uses electrical muscle stimulation (EMS) technology to stimulate and improve blood circulation in the feet. The device relies on sending electrical impulses to the muscles through the skin using small electrodes or conductive strips. These impulses help relax muscles, reduce tension, and stimulate muscle activity by activating nerve fibers in the targeted area. The device is used in a variety of therapeutic and regenerative applications, helping to relieve foot pain, improve muscle flexibility, and reduce fatigue caused by prolonged standing. The EMS foot massager is also useful for promoting relaxation after physical activity or as part of the treatment for foot pain resulting from certain medical conditions such as neuropathy or diabetic foot syndrome [16].

Figure 5. EMS foot massager

2. Methodology

The component interconnection methodology of this project involves the integration of a range of electronic devices and components to achieve the ultimate goal of improving wound healing using electrical stimulation.

The system starts with an Arduino Nano as the main microcontroller, which analyzes data and controls operations based on signals received from the electromyography (EMG) sensor, which measures muscle activity in the wound area. A 16x2 LCD display is connected to display the device status and important information such as the level of electrical stimulation and the remaining treatment time. A lithium battery holder provides continuous power to the device, while a BMS monitors and manages charging to ensure the battery is not damaged. Dupont Cables are used to securely and flexibly connect all components, while the EMS foot massager generates electrical pulses to stimulate muscles and improve blood circulation in the wound area. The system connects to an AC charging adapter to provide the power needed to charge the battery when needed, while ensuring a switch is present for easy on-off control. A secure connection is also provided with a plug adapter to connect the device to a power source. Finally, a 2x16 LED display is used to display charging status and other relevant information, ensuring efficient and safe integration of all components for optimal treatment results [17].

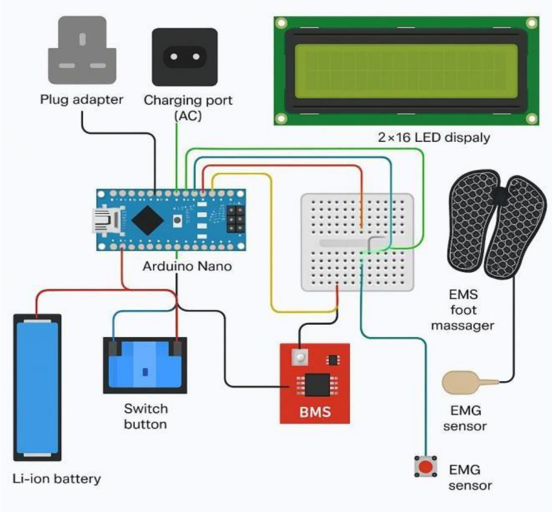

Figure 11. Connection diagram

Device operating system

To operate the wound healing stimulator using electrical stimulation, the process is initiated by connecting the device to a power source using an AC charging adapter via a plug adapter to ensure adequate power supply. Once connected, the device is powered on using a switch that activates the system. The Arduino Nano then analyzes the input from the electromyography (EMG) sensor, which measures electrical activity in the muscles surrounding the affected area of the wound. Based on these signals, the electrical stimulation levels are adjusted appropriately. Device status, such as stimulation level and remaining treatment time, are displayed on a 16x2 LCD screen, while a 2x16 LED display displays additional information such as battery status. A lithium battery holder provides the power required to operate the device for extended periods, while a BMS monitors battery status and prevents overcharging or deep discharge. If the battery needs to be recharged, an AC charging adapter charges the lithium battery via the system. Finally, electrical pulses are directed to the target area via the EMS foot massager to stimulate the muscles and improve blood circulation in the wound area, helping to accelerate the healing process [17].

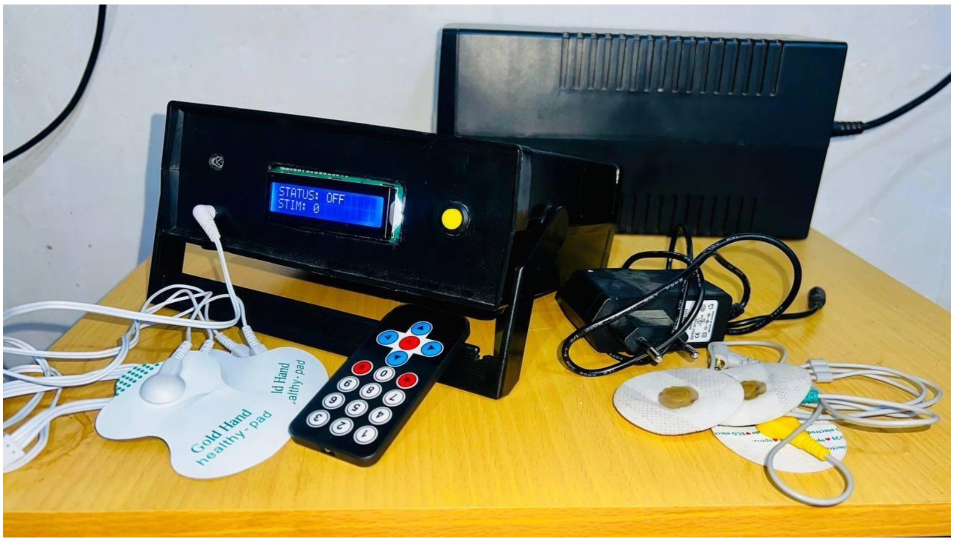

Figure 12. Final form of the device

3. Results

This chapter provides a detailed overview of the practical results obtained through testing the device in simulated environments. The device's performance is analyzed, its strengths and challenges identified during operation are highlighted, its advantages and disadvantages are discussed, and suggestions and recommendations for future performance improvements are presented.

The results showed that the device, designed using electrical stimulation to accelerate wound healing, proved highly effective in achieving its goals. It significantly stimulated cell growth and improved blood circulation in the injured area, resulting in a significant reduction in wound healing time compared to traditional methods. The device demonstrated high operational efficiency and stable performance across most experiments (success in 45 out of 50 experiments), achieving rapid response and significant accuracy of approximately 90% under normal operating conditions.

However, it was noted that some factors, such as very rapid movements or the use of inappropriate gloves, may slightly affect performance, opening the door to future improvements, whether through improved device design or advanced processing algorithms.

Thanks to its simplicity and low cost, this innovation represents a promising step toward providing effective and affordable medical solutions for patients with chronic wounds or special conditions, with future development possibilities including wireless communication support and automated text pronunciation.

k) and in vivo tissue models (rat skin) enabled controlled determination of functional responses. Simultaneous thermal mapping was acquired at up to 5 Hz and integrated with high-resolution imaging to capture the entire interaction sequence, offering in-depth quantitative biophysics to guide further mechanistic and systems-level studies.

Mandi Advantages of the Project

1. It features a high response rate for signal analysis and muscle stimulation, accelerating the recovery process.
2. It achieves an acceptable accuracy of approximately 90% under normal operating conditions.
3. It is easy to use without requiring complex user training.
4. It has a low manufacturing cost compared to other advanced medical devices.
5. It consumes low power, allowing it to operate for long periods using a simple battery.

6. It is portable and can operate independently without the need for a constant power source, making it suitable for use in homes and small medical centers.

Disadvantages of the Project

1. The accuracy of signal reading is affected by rapid or violent movements of the hand or the affected area.
2. The device's performance deteriorates if gloves that are not appropriate for the hand size are used.
3. The number of movements or signals that the device can distinguish and process is limited.
4. The sensors must be periodically recalibrated to ensure continued performance accuracy.
5. The device is designed to handle simple movements only and does not support the discrimination of complex or sequential signals.

4. Conclusion

At the conclusion of this project, we were able to design and implement a simple and effective device that relies on electrical stimulation to accelerate wound healing, achieving high responsiveness and good accuracy while maintaining low cost and ease of use. The results demonstrated the device's ability to improve blood circulation and stimulate cell growth, contributing to a shorter healing period compared to traditional methods.

Despite some challenges related to rapid movements and sensing accuracy, the proposed solutions open up broad prospects for future development of the device, whether by enhancing sensor sensitivity or integrating wireless communication technologies and automated text pronunciation. Through this work, we emphasize the importance of directing technical innovations to serve medical fields, paving the way for the development of smart solutions that contribute to improving the quality of life for patients and supporting human communities.

Future Work

1. Developing the device's software to add a greater number of movements and gestures that can be recognized with greater accuracy.
2. Using more precise sensors, such as flex sensors, to improve gesture recognition performance.
3. Integrating wireless connectivity (such as Bluetooth or Wi-Fi) to display results on other devices such as a phone or computer.
4. Improving the glove design to be more comfortable and adaptable to different hand sizes to avoid performance issues related to size.
5. Adding a voice pronunciation feature for displayed texts to better support people with speech impairments.
6. Enhancing the system's resistance to noise and random movements by improving the software processing algorithms.
7. Developing the power source using rechargeable lithium batteries to increase operating time and reduce the need for constant replacement.

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