JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

A Review on Muscle Stimulator

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Abstract: Electrical stimulation (ES), alternatively referred to as neuromuscular electrical stimulation (NMES) and transcutaneous electrical stimulation (TES), entails the application of electrical currents to activate nerves or nerve endings that connect to muscles beneath the skin. The prevalence of muscle disorders is on the rise, driven by sedentary lifestyles associated with corporate jobs and decreased physical activity. Additionally, a considerable number of individuals sustain muscle injuries through sports or accidents. In many instances, these individuals require muscle stimulation treatment to restore nerve sensitivity. The use of muscle stimulators is a common practice in addressing such cases.

Index Terms - Muscle Stimulator, Electromyography, Bio-amplifier sensor

I. INTRODUCTION

A muscle stimulator, also known as electrical muscle stimulation (EMS) device, is a technology designed to elicit muscle contractions through the application of electrical impulses. This innovative tool has found applications in various fields, including rehabilitation, sports training, and aesthetic purposes. By delivering controlled electrical currents to the muscles, these devices can help enhance strength, improve muscle tone, and facilitate recovery from injuries. Muscle stimulators have become popular in both medical and fitness settings due to their ability to target specific muscle groups and provide a range of therapeutic benefits. EMS also referred to as Neuromuscular Electrical Stimulation (NMES), involves inducing muscle contractions through the use of electric impulses. Over the past few decades, EMS has seen widespread utilization, serving various purposes, including therapeutic applications for immobilized patients and as a tool for strength development in athletes.

This approach effectively reinstates and enhances muscle tone and is also employed in addressing medical conditions characterized by muscle mass loss. In the realm of sports and fitness, EMS serves as a supplementary component to traditional training, aiming to stimulate specific muscle groups for heightened strength, efficiency, or aesthetic improvement. Varied levels of muscle contraction are attained by administering electric pulses of different types, depending on the chosen program. These contractions reactivate muscles, bolstering their efficiency and endurance, and prove particularly beneficial for muscles that have been underutilized or experienced atrophy for various **reasons.**

II. ELECTROMYOGRAPHY (EMG)

EMG is a methodology grounded in experimentation, aimed at assessing and capturing a sequence of electrical signals originating from the muscles in the body. The electrical representation of neuromuscular activation occurring in muscles during both contraction and relaxation is referred to as EMG signals. The electrical manifestation of neuromuscular activation occurring in muscles during either contraction or relaxation constitutes the formation of EMG signals. At any instant, the shape of the muscle signal, motor unit action potential (MUAP), is constant unless there is movement of the position of the electrode or biochemical changes in the muscle due to changes in contraction level. It is widely used to measure muscle response or electrical activity in response to a nerve's stimulation of the muscle.

III. MUSCLE STIMULATOR

In this work, an inverter circuit is employed alongside electrodes and a bio-amplifier sensor to investigate muscle activity. Initially, electrodes are placed on the target muscle to capture bio-potential signals during hand movement. The bio-amplifier sensor amplifies and records these signals, effectively monitoring muscle activity. Subsequently, the inverter circuit is introduced, although its precise role in the setup is not clearly defined. It might serve to manipulate or control the bio-potential signals.

A potentiometer is utilized to modulate the potential applied to the muscle, enabling the adjustment of stimulation levels. The bio-amplifier sensor records bio-potential values produced by the muscle in response to this stimulation. It is essential to recognize that this setup appears unconventional, as EMG is traditionally used for monitoring muscle activity rather than stimulating it.

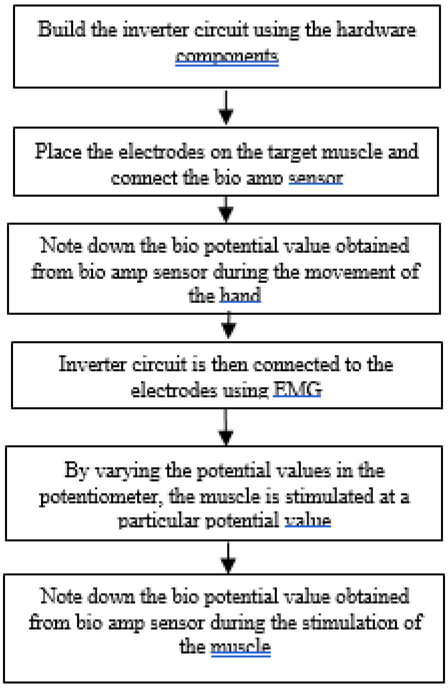

Figure 1. Flow chart for Methodology

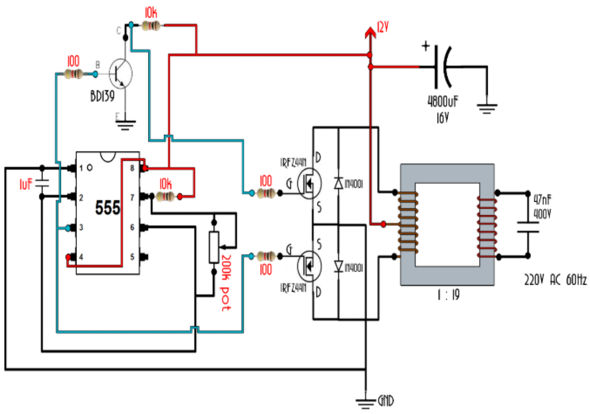

Figure 2. Inverter circuit using IC 555 Timer

IV. LITERATURE REVIEW

Ahmet Yardimci [1] presented a compact and cost-effective muscle stimulator designed for rehabilitation, sports health, and aesthetic purposes, distinguished by its exceptional portability, affordability, minimal power consumption, and robust security features. The device utilizes a microcontroller to generate customizable electrical pulses, allowing users to adjust pulse width, repetition rate, treatment duration, and specific programs tailored to individual requirements. Safety features are seamlessly integrated to prevent unintended activation and ensure secure energy output, with the convenience of battery operation for optimal portability. The document explores the diverse applications of muscle stimulation, ranging from muscle development and coordination to improving blood circulation, treating incontinence, and addressing cellulite. Emphasis is placed on cautionary measures, advising against usage for individuals with certain medical conditions, such as pacemaker users, those with heart rhythm disorders, allergies to electrode contact points, and pregnant individuals.

Md. Latifur Rahman , Md. Jahin Alam , Nayeed Rashid , Lamiya Hassan Tithy , Alfaj Uddin Ahmed and M Tarik Arafat [2] presented the report which explores the creation of an economically viable muscle stimulator tailored for biomedical applications, with a specific focus on patients grappling with muscle disorders. Utilizing Neuromuscular Electrical Stimulation (NMES), the authors propose an Internet of Things (IoT)-integrated device, prioritizing affordability, safety, and user-friendly operation. This IoT incorporation facilitates real-time data analysis, remote control, and data storage, empowering patients to independently utilize the device. Noteworthy features encompass a current protection mechanism guarding against tissue or muscle damage due to excessive current. Operating through voltage sources, a control unit for mode selection, pulse amplitude control, current protection, and WiFi connectivity, the IoT integration enables remote device control and data transmission to a cloud server for storage and analysis. Performance considerations encompass output accuracy, latency, data economy, and cybersecurity. Experimental results validate the device's adherence to standard output values, minimal latency, and robust data security. The authors underscore the significance of this low-cost, IoT-enabled muscle stimulator in advancing healthcare accessibility and suggest potential future enhancements, such as integrating machine learning algorithms to further elevate the device's efficacy and reliability for widespread public use.

Ratko Pavlović, Drena Trkulja-Petkovićand Stanislav Dragutinović1 [3] proposed the paper which investigates the utilization of electro-muscle stimulation (EMS) within the realm of fitness and sports, addressing the expanding landscape of fitness centers and diverse programs dedicated to optimizing training outcomes and transforming anthropological well-being. Specific focus is placed on its role in strengthening targeted muscle groups, facilitating muscle recovery, and supporting rehabilitation efforts. The Russian Protocol for EMS is introduced, detailing parameters such as frequency, amplitude, contraction duration, and the number of contractions. The physiological mechanisms of EMS, involving electric impulses stimulating nerves innervating specific muscle groups, are elucidated. EMS is achieved by an electric impulse which, via electrodes on the skin stimulates nerves that innervate specific muscle group as shown in Figure 3. The paper underscores EMS's potential to enhance muscle strength, endurance, and recovery in sports and fitness, while addressing associated precautions and contraindications, urging responsible application. The authors advocate for further experimental research to comprehensively grasp the scientific and practical implications of EMS in professional sports and fitness.

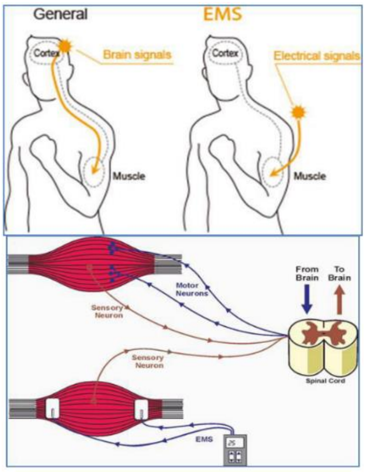

Figure 3. Stimulation of motor neuron (EMS)- afferent and efferent impulse .

N. Berger, W. J. Ohley, 0. Lemaire, and J. Parziale[4] proposed the creation of a portable muscle stimulator tailored for transcutaneous Functional electrical stimulation (FES), specifically developed to aid in the rehabilitation of individuals with spinal cord injuries. The stimulator features a single channel of current-controlled output and incorporates multiple safety measures to safeguard against device failure or miscalibration, ensuring patient well-being. Through six prototypes tested in an FES study at Rhode Island Hospital, the preliminary results indicate the stimulators' safety, reliability, and efficacy in delivering muscle stimulation for spinal cord injury patients. The design focuses on generating current-controlled rectangular pulses of preset duration and frequency, primarily targeting quadriceps exercise. Adjustable parameters include pulse duration, pulse frequency, and maximum output current. Tested on spinal cord injury patients, the stimulator exhibited positive outcomes in terms of muscle strength, endurance, and overall health during a six-week trial with no reported circuit failures. The study highlighted the device's good current regulation across varying impedances and its well-received usability by patients, who demonstrated the ability to operate it safely without assistance.

Brian Smith, P. Hunter Peckham, Michael W. Keith, And Dennis D. Roscoe, [5] details the creation of an implantable muscle stimulator geared towards reinstating controllable limb function in individuals with high-level spinal cord injuries. This compact and lightweight stimulator, designed for permanent use, is externally controlled and powered by a single encoded radio frequency carrier, offering up to eight independently controlled stimulus output channels as shown in figure 4. Employing constant current biphasic stimulus pulses, the stimulator's circuitry is encapsulated in both glass-ceramic and titanium packages for extended evaluation in animal studies. The use of semicustom integrated circuit technology ensures low power consumption and high reliability. The control logic integrated circuitry allows external control over channel selection, stimulus pulse width, and inter pulse interval. Emphasizing the importance of long-term protection within the body's internal environment, the document discusses the packaging of the implantable stimulator, detailing the criteria of sterilizability, mechanical resilience, and biocompatibility. The system is designed to interface with patient-portable, patient-controlled microprocessor systems, enabling coordinated limb control.

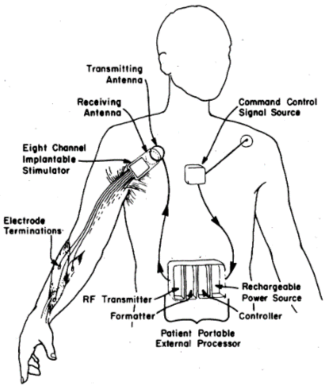

Figure 4. System for restoration of hand function in spinal cord injury patients

Haibin Wang, Guan Guan, Qing He, Dewen Zeng, Bin Leng, Hongwei Xu, Weiming Zheng [6] proposed a method for the construction of an Electrical Muscle Simulator utilizing FES for rehabilitation, underscoring FES's significance in reinstating nerve and muscle function, especially in improving hand function and lessening the psychological burden for individuals with disabilities. It introduces fundamental electrical stimulation principles, covering effective stimulus conditions, waveform types, and parameters such as current intensity, pulse width, and stimulation frequency. The simulator's capacity to generate stimulating waves at various frequencies is highlighted, ensuring consistent and efficient muscle contractions. The document concludes by envisioning future enhancements, suggesting the integration of feedback mechanisms, visual training, and assessment systems to elevate the simulator's efficacy in restoring nervous system control for pelvic floor muscle rehabilitation.

Muhammad Farhan Azman, Amelia Wong Azman, Siti Mohd Ariff [7] developed a method that delves into the utilization of Electrical stimulation (ES) to enhance muscle tone, size, and strength, particularly within the realm of rehabilitation. The study, conducted on five subjects, explored the impact of ES on muscle properties, including bulk, size, tone, atrophy, and strength. Results indicated that ES in isolation could enhance muscle properties, albeit with certain limitations and precautions, suggesting its potential utility in rehabilitation programs. Using the MediStim XP EMS stimulator, the study administered ES therapy to the upper limb muscles of test subjects over a three-month period, revealing that while ES effectively promoted muscle bulk, it did not independently increase muscle strength. The study also explored the linear relationship between EMG signals and isometric mus cle contraction force, highlighting valuable insights for future research.

Michael John McNulty, Padraig Fogarty [8] proposed a design considerations for an advanced Electrical Muscle Stimulation (EMS) circuit, with a specific focus on achieving high efficiency. EMS involves the application of pulsed electrical current to stimulate muscle motor points, inducing muscle contractions. The emphasis is on the importance of minimizing size and enhancing power efficiency, particularly for implanted and externally worn EMS devices. The block diagram of the proposed system is shown in Figure5. With pulse widths ranging from 50µs upward, transient time of the order of 10µs or less are required. The document critiques the inefficiencies of existing EMS output stages, citing fixed voltage rails and constant current circuit stages as contributors to power losses. In response, the proposed EMS output stage aims to eliminate such inefficiencies by generating only the necessary voltage to deliver the desired load current. The design operates as a closed-loop feedback control system, dynamically adjusting the output voltage to maintain the load current across the entire load impedance range. Simulation results demonstrate the system's stability and efficiency in delivering short EMS pulses. Overall, the proposed EMS output stage presents a notable advancement in energy efficiency compared to existing solutions.

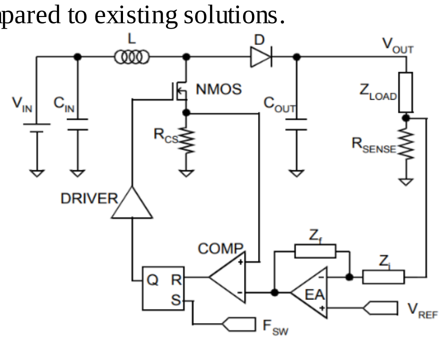

Figure 5. Proposed EMS Circuit

Sahil Gera and Naveen Gangadharan [9] in this article explores the application of Functional Electrical Stimulation (FES) for treating denervated muscles resulting from lower motor neuron (LMN) injuries, emphasizing the associated challenges and introducing a novel stimulator and muscle contraction sensor designed for this purpose. In a study involving three subjects with LMN injuries, a month-long FES therapy utilizing a high-strengh stimulator, named CMCstim, demonstrated improved responses in denervated muscles, showcasing the potential for enhanced FES to restore muscle bulk and prevent atrophy in peripheral nerve injuries. The CMCstim stimulator, featuring eight channels for major lower limb muscles, delivered ultra-long electrical biphasic pulses and was powered by a rechargeable lithium-ion battery. Additionally, a novel muscle contraction sensor, employing a strain-gauge load cell, offered a simple and reliable method for assessing muscle fiber composition and strength by measuring limb girth changes during muscle contraction. The study's protocol, involving electrode placement and regular stimulation sessions, yielded significant increases in muscle twitch responses, suggesting the efficacy of home-based FES in activating and strengthening denervated muscles. Overall, the study underscores the safety and effectiveness of the novel stimulator and muscle contraction sensor, while also contributing insights into muscle twitch measurement and the potential for preventing atrophy in peripheral nerve injuries through enhanced FES.

Jonathan Castelli, Florian Kölbl, Ricardo Siu, Gilles N'Kaoua, Yannick Bornat, Ashwin Mangalore, Brian Hillen, James J. Abbas, Sylvie Renaud, Ranu Jung, Noëlle Lewis [10] proposed a document which details the creation of Multistim, a fully configurable IC-Centered stimulator specifically designed for investigating muscle stimulation paradigms, with a particular focus on respiratory pacing experiments in vivo. Multistim offers eight current stimulation channels with high-voltage compliance and real-time operation capabilities, making it versatile for a broad range of FES applications. Its architecture comprises a full-custom integrated circuit (ASIC) and an FPGA-based digital design. The analog component generates current pulses based on the FPGA-managed stimulation parameters, providing real-time control. The system includes multi-platform Graphical User Interface (GUI) software and an Application Programming Interface (API) for stimulator control. In preliminary FES experiments, the stimulator demonstrated successful functionality in standalone and closed-loop setups. In in vivo validation experiments on rodents, particularly in diaphragm pacing open-loop experiments, Multistim effectively delivered stimulation pulses, resulting in increased natural lung volume. Experiments show, as expected, an increase of the natural lung volume when stimulation is on figure 6. The document highlights its efficacy in preliminary FES experiments, with future plans to interface the stimulator with a computer-based closed-loop controller for more advanced applications.

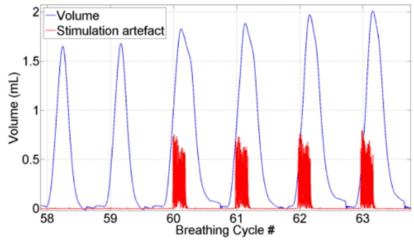

Figure 6: Simulation cycle

Figure 6. Representative stimulation cycles of the breath volume variation. At breathing cycle #60, the stimulation is turned on (stimulation artefact visible on red track). Natural lung volume is increasing from 1.6 mL when stimulation is off, towards 2 mL when stimulation is on. Cathodic/anodic pulses amplitude, duration, interphase and frequency are respectively set to 1 mA, 400 µs, 40 µs and 75 Hz. Stimulation burst is delivered each 200ms.

Santa C. Huerta, Massimo Tarulli, Aleksandar Prodic , Milos R. Popovic and Peter W. Lehn1 [11] presented an innovative architecture for a Functional Electrical Stimulation (FES) system, devised to deliver electrical pulses to nerves or muscles for the restoration of lost motor activity. This new system distinguishes itself by offering a broader range of stimulation pulses, minimizing pain sensation, and significantly reducing power consumption compared to existing solutions. Notably, it eliminates the need for a dedicated discharging circuit by ensuring zero net charge of stimulated tissue. At its core, the system features a digitally controlled multi-output power stage that combines flyback and switch-capacitor converters to generate high-slew rate pulses with zero net charge. Experimental results from a four-channel prototype demonstrate independent channel control, noise-free pulse shapes, ultra-fast current slew rates, and reduced pulse amplitude requirements for muscle contraction. Comparative clinical trials showcase the improved performance of the new stimulator, with approximately 1.5 times lower pulse amplitude needed for the same muscle contraction and significantly increased battery life.

Valery Puebla , Josselyn Ruales , Diego S. Ben´ıtez and Marcello Longo [12] proposed the document which explores the application of controlled electrical stimulation to mitigate muscle atrophy during the treatment of fractures with immobilization splints. The proposed prototype system incorporates electrodes within a 3D-printed splint to emit intersecting waves, stimulating muscles during immobilization. Featuring an oscillator circuit with two timers for generating stimulating pulses, the splint is designed to offer enhanced breathing and stability compared to conventional plaster or fiberglass casts. The study aims to evaluate the effectiveness of this system in preventing muscle atrophy during limb immobilization. The method section details the development of the 3D-printed splint and the electrical stimulation circuit, emphasizing safe and controlled current levels. Experimentation involving healthy subjects demonstrated that electrostimulation, in conjunction with immobilization, resulted in reduced muscle mass loss compared to sole immobilization after 20 days. The study underscores the potential of electrical stimulation in maintaining and exercising muscles during immobilization, advocating further research to validate the system's performance in real fracture cases and extend the study to various limb fracture types.

Pedro Lopes and Patrick Baudisch [13] proposed the utilization of Electrical Muscle Stimulation (EMS) for the creation of interactive systems and human augmentation. EMS devices employ electrical impulses to induce involuntary muscle contractions, facilitating the actuation of the user's limbs. Various prototypes are presented, illustrating potential applications such as integrating force feedback into games, controlling video playback, simulating resistance in virtual reality, and replicating haptic sensations of impact. The authors underscore EMS's advantages, including its compact form factor, capability to reach challenging body areas, and potential for seamless integration into human-computer interfaces. Comparisons with traditional mechanical actuation highlight EMS devices' smaller size and the ability to leverage the user's skeleton and muscles rather than introducing additional mechanical components. The article explores both the strengths and limitations of EMS systems, acknowledging their ability to reach difficult-to-actuate body parts while noting limitations in precision and reliance on the user's physical strength. It concludes by suggesting future directions for EMS research, emphasizing improvements in electrode placement, actuation precision, and user voluntary motion sensing. In summary, the article provides insights into the potential applications of EMS, its comparative advantages, and outlines avenues for advancing EMS technology.

Alkinoos Athanasiou, Panagiotis Bamidis, Alexander Astaras [14] proposed a document that outlines a novel electrical muscle stimulation device designed for neurorehabilitation employing Functional Electrical Stimulation (FES) to induce muscle contractions. The authors underscore the significance of optimizing parameters like pulse intensity, frequency, pulse width, and time delay between pulses to enhance muscle contraction intensity and minimize discomfort. They introduce an AI algorithm for adaptive parameter optimization, aiming to automate and calibrate FES parameters for individual subjects at the onset of each session. The hardware configuration incorporates microcontrollers, a waveform generator, an accelerometer, and an oscilloscope. Software development involves programming microcontrollers to monitor muscle acceleration and control the signal generator. Preliminary experiments display graphs correlating maximum acceleration with voltage and frequency, suggesting potential optimal parameter values. Acknowledging the need for more subjects and diverse electrode placements, the authors plan to expand the study to include various waveforms, electrode positions, and additional parameters. The authors aspire to further refine their approach by increasing subject numbers, exploring different parameters, and incorporating machine learning to create more personalized and effective rehabilitation protocols for patients.

Yusuke Takei, Toshihiro Takeshita, Daniel Zymelka, and Takeshi Kobayashi[15] described the development of a probe designed to assess muscle contraction characteristics through electrical stimulation-induced mechanomyogram. Comprising two electrodes for electrical muscle stimulation and an ultra-thin piezoelectric membrane for mechanomyogram measurement, the probe analyses the speed of contraction in fast and slow-twitch muscles. The focus of the study is on using this technology to evaluate the shift from slow to fast-twitch muscles as a predictor of frailty, especially in the elderly. The probe successfully demonstrated its capability by assessing the improvement of gastrocnemius muscle elasticity with physiotherapist treatment, specifically measuring the impact of massage therapy on relieving ankle contractures. While the treatment temporarily adjusted the elasticity of fast-twitch muscles, with aligned contraction speed, the effect diminished after 90 minutes. Figure 7 shows the measurement of electrical stimulation-induced mechanomyogram with the probe and an example of the measured data.

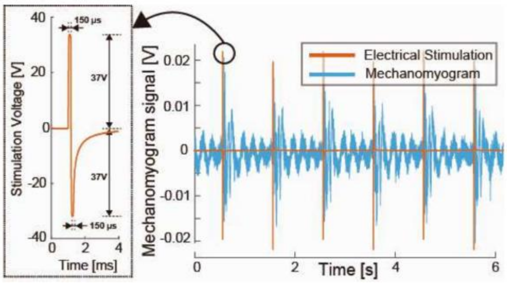

Figure 7. Electrical stimulation and mechanomyogram measured by the probe.

V. COMPARISON TABLE

Ref. no	Advantages	Remarks
2	Cost efficiency, accessible to a larger population.	Integrating machine learning or deep learning to mitigate IoT latency, improving efficiency and reliability.
6	EMS is used in clinical settings and to study the mechanism of Functional Electrical Stimulation (FES).	Future work to enhance EMS design for more effective rehabilitation strategies..
7	Electrical stimulation (ES) can improve muscle bulk and size, which is beneficial in rehabilitation programs.	ES alone cannot significantly increase muscle strength, requiring additional functional activities or exercise to achieve this.
8	Significantly higher theoretical efficiencies resulting in minimal power wastage during stimulus delivery.	The challenge lies in designing a control loop that ensures stability and fast transient response under all load conditions.
9	Portable and high-strength stimulator, benefit individuals with lower motor neuron injuries.	No device-related issues or side effects observed; initial slow response to stimulation noted.
10	Real-time operation capabilities enable a wide range of FES applications.	Future experiments may face limitations due to voltage constraints.
11	This FES system produces pulses with a 10ns rise time, resulting in the same muscle force output for 30+% less stimulation energy.	New FES system consumes 60% less energy, prolonging battery life for portability
12	Electrical stimulation can maintain and exercise muscles, reducing atrophy	More studies needed to test system performance with real fractures, as athletes may still face muscle loss.
13	EMS devices are smaller than	EMS enables seamless human augmentation for

	traditional mechanical actuators, suitable for wearable applications.	enhanced learning of physical tasks..
14	The device reduces discomfort and muscle fatigue during rehabilitation sessions.	Further experimentation with larger sample size and diverse methods required for conclusive results.

VI. CONCLUSION

Muscle stimulators, particularly electrical muscle stimulation (EMS) devices, are transformative technologies with diverse applications in rehabilitation, sports training, and aesthetics. These devices, also known as Neuromuscular Electrical Stimulation (NMES), play a crucial role in controlled muscle contractions, contributing to improved strength, tone, and injury recovery. The widespread adoption of EMS underscores its efficacy in both medical and fitness contexts. Ongoing efforts to develop an affordable and functional muscle stimulator aim to overcome financial barriers and broaden access to this technology. The potential inclusion of data collection and analysis capabilities promises advancements in tracking progress and optimizing EMS for personalized outcomes over time. Overall, muscle stimulator technology holds significant promise for diverse applications, promoting advancements in healthcare, fitness, and aesthetics.

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VIII. ACKNOWLEDGMENT

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