IoT Based Cost Efficient Muscle Stimulator for Biomedical Application

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***Abstract*—The number of patients with muscle disorders are increasing day by day for corporate jobs and less physical activity. Moreover, many people injure their muscles from sports or accidents. In most of these cases they need muscle stimulation treatment to gain the nerve sensitivity back. Muscle stimulator is frequently used in such cases. However, most of the people cannot get the service of a physiotherapist every day for muscle stimulation. On the other hand, the muscle stimulators are very costly and hard to use. Several conditions of muscle need a change of settings of the machine which also requires experts help. For this purpose, this paper suggests an Internet of thing (IoT) based cost efficient muscle stimulator which combines the facility of being affordable, providing better safety for current and easy to operate. This process can further be integrated with telemedicine and a smart hospital system.**

***Keywords*—Muscle Stimulator, IoT, Current Protected Device**

I. Introduction

Electrical muscle stimulation (EMS), is the evocation of muscle contraction using electric impulses, also known as Neuromuscular Electrical Stimulation (NMES). EMS is used in an enormous amount in the last few decades, comprising several areas such as therapeutic tools for immobilized patients, strength developing tools for sportsmen [1], [2]. EMS methodizes the use of electrical impulses mimicking the action potential that comes from the Central Nervous System (CNS) to incite skeletal muscle cells and develop contraction [3]. To assess Neuromuscular Function (NMF) this device can provide the adjuvant signal enhancing the rehabilitation of muscles [4], [5]. The work presented in this paper is an IoT based device for EMS.

IoT has radically changed modern healthcare systems and management. IoT offers its greatest promise to deliver excellent progress in the healthcare domain [6]. Although it has come into reality, critical problems still exist in automating design and reconfiguration of such a system enabling it to respond to the patient's requirements rapidly [7].

Using IoT in a muscle stimulator, we can constantly analyze real time data signals and combine them to optimize the value streams and capture according to storage capacity [8]. Patients themselves can use this device without any need of expert's presence. Furthermore, physicians can easily examine the current condition of the patient and change any part of the treatment.

The relation between muscle force and its electromyographic (EMG) at the time of stimulation has been studied [9]. Nevertheless, it does not serve as a therapeutic or rehabilitation device. An electrical muscle stimulator is also presented that is mainly devoted for exercise purposes [10]. Despite being wearable, this was not up to the mark for therapeutic purposes as it requires a device to control its input every time it is used. And it cannot be controlled online or the usage can't be stored online. Another cost effective device quantified the degree of fatigue in an efficacious way [4]. However, the device could be user friendly if it had IoT, data conservation for future use and different inbuilt protection features. Thus, an IoT based muscle stimulator which is cost effective and easy to use is imperative to develop.

In this paper we have built a muscle stimulator that can be operated using IoT connectivity or manually. Integration of IoT in muscle stimulators increases its usability several times. Using IoT will help people to operate the muscle stimulator by themselves without the risk of endangering the patient.

II. Segments of Device

Muscle stimulators are used for their rehabilitation and functional purposes. When we give stimulation voltage on skin, some fraction of voltage converts into current as there variable skin impedance exists on the body. The higher the carrier frequency we use, the lower the skin impedance becomes. The motor points receive the current signal and can not distinguish between the stimulator current and the signal coming from cerebrum. From motor point, the current goes to muscle fibers

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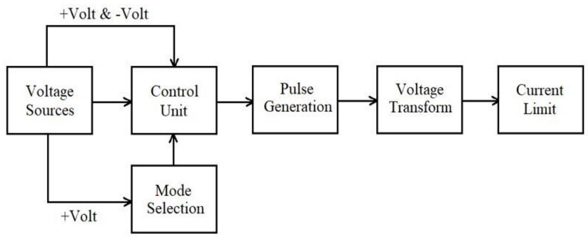


Fig. 1. Block diagram of operation system.

and strengthen weak muscles. It can also be used to relieve pain. Muscle stimulator sends electrical signals through the nerves to the brain which helps to release endorphin, a natural painkiller. Thus it reduces the pain.

This process is done using the steps discussed below

A. Operation System

The rudimentary aim of the muscle stimulator is to deliver a certain waveform of current into the muscle fibers. The overall system of operation is provided in Fig. 1. The voltage sources consist of both positive and negative voltages. The positive voltage is at 4.8V to 5V dc to operate all the integrated circuits in the subsequent segments. The negative voltage is required for the Op-Amps. An Atmega328P is utilized for controlling the attributes of the current. There are different modes, duration and frequency of the pulses which are user interfaces. The pulses are stepped up into higher levels of voltages which would penetrate the muscle at the required amount. Before inserting to the muscles a current protection feature is added to avert high levels of current that may cause damage to the tissues or muscle.

B. Control Unit and Mode selection

Having eleven programmable digital pins, the Atmega328P chip is sufficient for this purpose. In Fig. 2, we see a crystal (16 MHz) to upload code to the processor. There are 3 attributes of the device: (1) modes (Galvanic: 100% dc, Interrupted dc: 50% duty, Ferradic: 10-20% duty), (2) frequency and (3) time duration of the pulses. Three potentiometers are used for controlling three of these attributes by the user. A push button is there to confirm the starting of the device. The output from the chip is then buffered to the 'pulse amplitude control' circuit. A connector also arrives from the current protection circuit to the chip in order to read a 'reset' trigger if and after the device turns off automatically.

C. Pulse Amplitude Control

The chip output pulse is buffered using a UA741 operational amplifier and sent through a voltage divider. As shown in Fig. 3, a 1kΩ potentiometer is connected to a 220Ω resistor in series and that potentiometer output is buffered through another UA741. This provides a highest voltage accessibility of 4.098 Volts. Then it is again buffered and then amplified using a step up 220V/12V transformer. Therefore, the highest output would be 75.13 Volts. Positive and negative voltages of sufficient amplitude were used for biasing to ensure no saturation of the pulse in the op-amps

D. Current protection feature

The transformer output connects to the current protection circuit which uses relays and op-amps to control the current. One op-amp senses the current going through the muscle from a series resistor and compares it to a threshold value. If the threshold is exceeded, another op-amp turns off the main relay and the other relays keep the main relay turned off. Therefore the current is shut down. The 'reset button' can be pressed to re-inject current to the muscle and the device will continue running unless current exceeds again. The circuit and working principle of the feature is presented: K1, K2, K3 : Relays (5V rated); U1, U2 : UA741 Op-Amps (15V rated); Q1, Q3 : BJTs STIMU1 (1-2): Electrodes across skin R4 : Low value resistor series to skin resistance

E. WiFi connectivity

As we aimed to develop a low cost muscle stimulator device, our choice for the IoT device is the "ESP 8266 Development Board". In our system the ESP 8266 performs as a slave device to a host microcontroller. The microcontroller in the control unit uses serial communication to send its data to the ESP 8266 board as given in Fig. 2. Then the ESP 8266 Development Board uses it's WiFi module to send the data to the cloud server.

III. System overview and IoT integration

One of the main features of our developed muscle stimulator is the integration of the IoT platform in this device. The IoT devices make the muscle stimulator more user friendly and gives users greater control over the device. In our proposed model, there is a IoT device in the main circuit board that is connected with the control unit circuit's microcontroller as given in Fig. 3. In the selected mode, the amount of time pulse is applied and the amplitude of the pulse are the three pieces

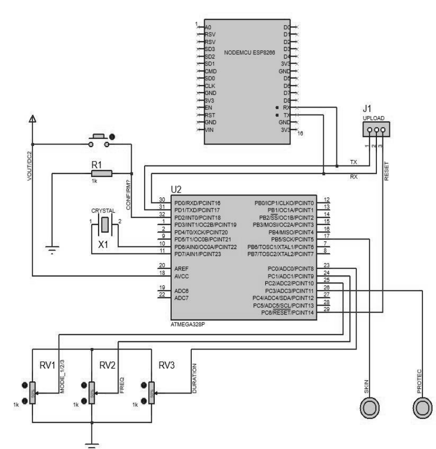


Fig. 2. Control Unit, Confirm Switch and Mode Selection

of information that are passed from the control unit to the IoT device. Also from the feedback system, information such as the magnitude of the current flowed and the receiving end voltage are also sent to the IoT device. This information can be used to determine how the muscle is responding to the applied pulse signals. The IoT device then sends all these data to a cloud server and the data are stored there against the ID of each user. These data then can be instantly sent to the cellphone of the user and the physiotherapist who recommended the muscle stimulation therapy. The physiotherapist can use this data to monitor the progress of the patient. Also there is a failsafe installed in the cloud system that if a user suddenly changes their settings dramatically or increases the magnitude too much, a warning message will be sent to their cellphone and the device will shut down.

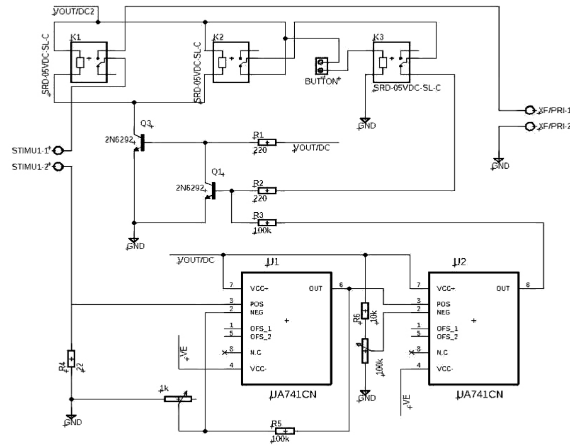


Fig. 4. Current Protection of the System

IV. Performance Consideration

A. Proper output delivery

As an electronic muscle stimulator its main goal is to stimulate muscle properly. The output of the device should match for each mode individually. And the control through IoT devices should be the same as offline input. The output needs to match with the standard value. And protection from all kinds of abnormalities should also be checked out. The output is checked and discussed in ”Section V” with relative outputs.

B. Latency

In our case Latency is the time difference between the user’s input through an IoT device and the response of the EMS. Latency is influenced by network availability, number of users, propagation distance and storage delay. Any of these causes can make the device slow and can hamper the performance of the device. For latency problems, under lower network connectivity, the device will operate on offline mode or with the input that was used last. Each user gets his/her own segment of server which reduces latency. And all kinds of data storing is done after the online command is executed, that further reduces the latency.

C. Economy of data usage

Considering the fact that a low cost device which most of the people can afford, the amount of data required for operating the device should also be low. It will save Both time and money if a lower amount of data is required for this operation. Otherwise the usability of IoT will fall. For the economy of data we have used only a few word based control systems like “Mode 1” which commands the device to operate on mode 1 or “V-70” which commands the device to provide voltage up-to 70V. It is also suitable for storage of data for further usage.

D. Cyber Security

Nowadays data security is a crucial matter. Here we use the four layer networking standard Transmission Control Protocol/Internet Protocol (TCP/IP). This is encrypted and the authentications layers will be secured. We do not use default ports, rather choose random ports to run the programs in the server. For providing the service, only the necessary ports will be kept open. The Wifi network is kept secured with WPA3 encryption. The user level permissions, doctor and nurse level persons (read, write and execution) are provided in an appropriate way and maintained strictly. To avoid botnet attack, the type of the data is monitored. If any different type of data is found that lets the server know as a threat. Then we patch and update necessary software regularly. Which keeps a log of every action in our programs and eliminates any unwanted route.

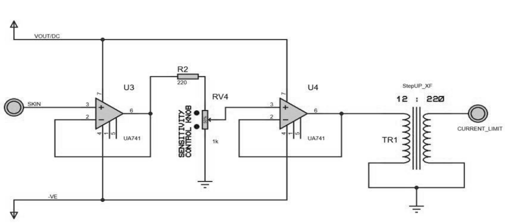


Fig. 3. Pulse Control and Buffering before Amplification

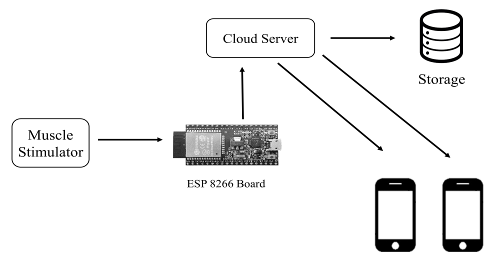


Fig. 5. Block Diagram of IoT Connected System

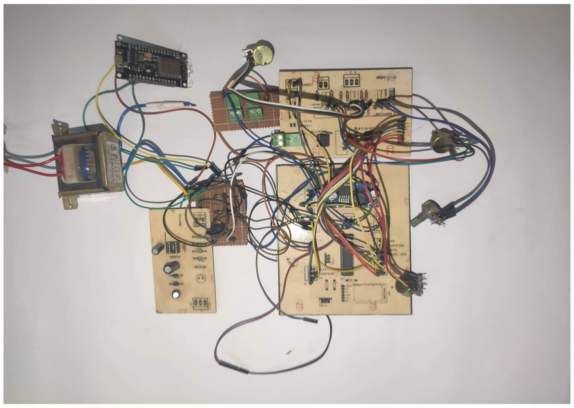


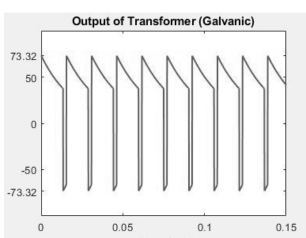
Fig. 6. Experimental circuit of EMS device

V. Experiments and Result analysis

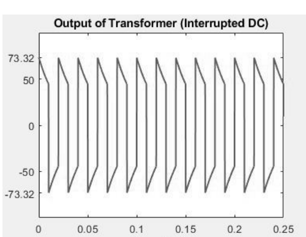
From the experimental circuit of Fig. 6 we see the results in Fig. 7.

Fig. 7 states that the voltage is within the limit of the standard value and frequency for different modes; the frequency is also within the range. And for any kind of current malfunction, the current protection circuit takes care of that. And the Latency of the product was pretty minimal; within 1.5 second any latency beyond 1.8 second is suggested to operate online. As data is sent only in text format so it is very affordable. And the cyber security is also increased enough. Moreover in case of failure of security, it won't hamper the patient that much as the input is always limited to 10% of previous input which concludes to satisfactory result from the EMS device.

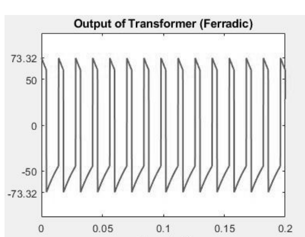
The cost of the device is around 50 US Dollar. The similar products cost around 100-200 US Dollars, depending on the brand and features. As the cost of the device is pretty low compared to other similar products, people can afford it easily.We mainly focus on usability of patients, ensuring the security of data. Moreover, the compact size of the whole device is quite appreciable compared to other EMS devices. We take care of the risks of e-stim that may include muscle tearing, tissue burn, or skin irritation by regulating the maximum voltage and current level in our internal circuitry. Besides a failure to properly assess the maximum electrical exposure can cause severe damage to the muscles and kidneys. Those obliterations are avoided and in our cloud any kind of discrepancy in the data will notify the user to stop immediately.



(a) Output of Transformer Galvanic



(b) Output of Transformer (Interrupted DC)



(c) Output of Transformer (Ferradic)

Fig. 7. Outputs of the EMS Device

VI. Conclusion

Increasing usage of Electronic Muscle Stimulator, a cost efficient Electronic Muscle Stimulator with greater usability with benefits of IoT is a demand of time. A low cost IoT controlled EMS has been realized with the connection and system that it would operate on. The circuit and all the output of each part has been examined with satisfactory results. Use of IoT helped to store and examine the previous data and control any mistake while operating. These features will help tele medicine and smart hospital systems to provide service to more people easily and with lower cost. In the future we will add a different learning algorithm, so that it can control the input autonomously under supervision of an expert. Addition of Machine learning or deep learning algorithms will make it more efficient and more reliable for public use.

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