MusCare: A Mobile Design for Muscle Monitoring

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Abstract – **Muscles not only help people move, but they also help the body work. However, muscular disorders have become common nowadays, such as Muscular Dystrophy (MD) and Muscle Atrophy (MA), which are genetic and lifestyle diseases causing the loss of muscle mass. The research question we have is whether Internet of Things (IoT) and mobile engineering techniques can help monitor muscle conditions, such as overuse of muscles, muscle recovery from surgery, etc. We propose *MusCare*, a microcontroller-based system with EMG sensors and an Android mobile app, to help monitor muscle status and visualize the results for the users. The current results show that the system can provide real-time monitoring results on a mobile device. In addition, a neural network algorithm was able to be implemented on a mobile phone to detect anomalies from the EMG data. Currently, the prototype system uses a MyoWare EMG sensor to keep track of the targeted muscle group, but the design of the system can be extended to work with vibrators to provide an advanced improvement in the interaction.**

Keywords* – *EMG sensor, Bluetooth, Microcontroller, Mobile App Development, Muscular Disorders

I. INTRODUCTION

Muscle disorders have become common nowadays and there are many problems to cause it, such as injury or overuse, genetic disorders, inflammation, etc. For example, SMA (spinal muscle atrophy) is a genetic neuromuscular disease characterized by muscle atrophy. According to the SMA foundation, SMA develops in the early stages of life and is the leading cause of death for infants and toddlers [36,18,19]. Duchenne Muscular Dystrophy (DMD), one of the most common muscle disorders, is found within 1 in 3,500 male births worldwide [25].

Both of SMA and DMD do not have an appropriate treatment to cure them, but consistently monitoring the condition can provide a good opportunity for the medical professionals to provide suitable support. In addition to monitoring the muscle group or groups, a device that can be used to massage the targeted area could be applied. This could be a form of short instant relief depending on the ailment.

To measure muscle condition, the Electromyography (EMG) sensor is an important component used in medical systems. EMG is the method of measuring electrical activity when muscles contract. When the muscle moves, it starts in the brain, i.e. the motor cortex. The signal is then sent through the spinal cord and to the location of the relevant muscle via the motor neurons. It begins with the upper motor neurons to the lower motor neurons. The lower motor neurons are the ones responsible for muscle movement and innervate the muscle directly at the neuromuscular junction. This causes the release of calcium ions creating a mechanical change in the muscle. The process involves depolarization which is what the EMG detects. The EMG amplifies the difference and suppresses common voltages within the body. This process is called differential amplification. EMG shows the intensity, order, and durations of muscle contractions.

The purpose of this research does not try to cure muscle disorders, but instead is to design a mobile health system, which can track, analyze, and produce a plan to help mitigate the issue. In the following paper, we will exam related systems in the related work section and move on to explain the hypothesis. In sections IV and V, the design and implementation of the system will be presented. The paper will conclude with the results, discussions and future work.

II. RELATED WORK

Some researchers have used Raspberry Pi and Arduino to develop systems to support health monitoring. For example, Khachfe et al. 's work presents a system that can monitor and keep track of soldiers on the battlefield [22]. The developed mobile application keeps track of the users' vital signs and activates certain measurements to help the users. The EMG application is similar but will not need to track the user via GPS due to the nature of the application [9, 16-19].

Researchers have been working on making a wireless health monitoring system by using multiple sensors [1-5]. For example, Nyni et al. 's work introduced a simple wireless system that extracts and monitors three bio-signals, such as EEG, ECG and EMG [1]. The entire system is wireless and compact by using dry electrodes stuck onto the body. Although the EMG application has a wireless capability, the size and mobility are not small as it stated.

Majumder et al. 's work of wearable sensors for remote health monitoring is another work dealing with wireless sensors for data transmission [6]. The paper discusses the application of using wearable sensors to track the physiological health of the elderly. The sensors can track and record real time data from the sensors which will provide a lower cost to healthcare as well as providing detailed information which can lead to a care plan to help improve and extend the users' lives.

On the other hand, Page et al.'s work deals with the ease of wireless monitoring and the data that comes with it [7]. However, the overwhelming amount of raw data might be difficult to read for the users. Similar to our work, this research analyzes EMG raw data. The data being tracked is shown as a graph. This would be useful for medical professionals to view such data, but the average person would prefer to see a customized figure.

Compared with other people's work, our research not only focuses on designing a mobile health system with EMG sensors, but we also use machine learning algorithms to find anomalies from the data and provide interactions.

III. Proposed Idea and Research Hypothesis

There are different kinds of diseases and one of them is related to muscles, such as muscular dystrophy (MD) and muscle atrophy (MA). MD is a group of diseases that cause progressive weakness and loss of muscle mass. In MD, abnormal genes interfere with the production of proteins needed to form healthy muscle. There is no cure for muscular dystrophy but with medications and therapy, it can be managed and slow the effects.

In this paper, we propose to use Internet of Things (IoT) techniques, EMG sensors and mobile application to help monitor muscular conditions, such as muscle pain, stiffness, increased weakness, etc. Electromyography (EMG) is an electrodiagnostic technique that can be used for evaluating and recording the electrical activity produced by skeletal muscles. We hypothesize that the proposed system can help monitor the specified region of muscles. Wearing the system over time can show if it is indeed an issue with the muscles in the region or if the issues are related to something non-muscular.

IV. System Design

The design of the system contains two parts: microcontroller-based system and Android mobile app. The microcontroller-based system is designed to work with EMG sensors, which can be used to measure the tightness of the muscles. We investigated a few possible solutions and decided to use Arduino Uno, Bluetooth breakout (nRF8001) and MyoWare EMG Sensor. The second part is an Android mobile application, which should be capable of receiving EMG data from the microcontroller-based system, analyzing them and providing an interface to interact with the system for the users. (Figure 2)

The Android mobile application did not require any hardware but the user's phone, which is where the application would be downloaded and run. To demonstrate the real-time data, the mobile application drew graphs to show the changes of the muscle. In addition, it should have an ability to run machine learning to learn and predict the muscle condition. Our system considered to transmit data via Bluetooth and use MPAndroidChart [27] to draw real-time data.

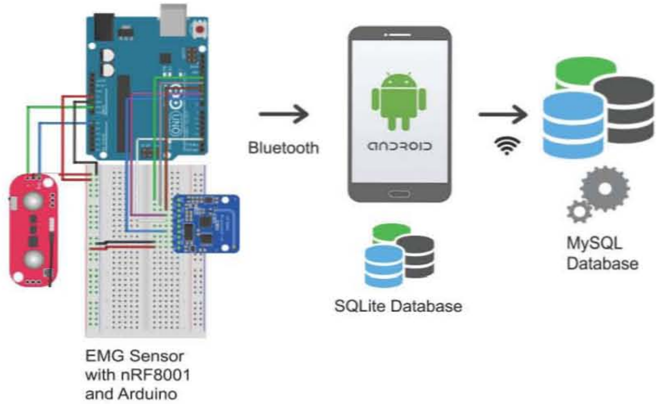

Figure 2. System Architecture

There are two types of EMG tests: the needle conduction and the nerve conduction. While the needle conduction inserts a needle electrode into the muscle and records the electrical activity inside of the muscle, the nerve conduction places electrode stickers to the skin surface to measure the speed and strength of the signals traveling between two points. Generally speaking, EMG readings can range between less than %0 uV and up to 30mV. In our system design, we considered to use MyoWare muscle sensor, which is able to measure and display the raw EMG signals, rectified and integrated signals. The rectified and integrated output from the MyoWare sensor will be analog, ranging between 0-1023. Arduino takes analog signals that are essentially a scale of voltage from 0V to 5V of electric inputs, which is the maximum value of 5V divided into 1024 levels.

In order to provide data analysis to the collected EMG data, we also considered applying a machine learning algorithm into our mobile application. Specifically, we considered neural networks, which was also implemented in the design of the system. The goal of the usage is to detect anomalies of muscle activity. With neural networks, collected data can be added into the process to learn and train the network and the outlier data can be found and displayed to the user. The schematic of a neural network can be illustrated as Figure 3.

In neural network, we define multiple layers and each layer contains multiple neurons, which receive input from previous layers and generate output to next layer. Neuron can be considered as a function, such as exponential function. In addition to input and out layers, it also has multiple hidden layers in between. For having a neural network in the mobile device, we investigated and used DL4J [41], which is a Java library and can be used in Android environment. For any neural network built with DL4J, the foundation is laid with

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the `NeuralNetConfiguration` class. It is also where hyperparameters and quantities that define both the architecture and how-to algorithm learn. Each circle or node in the hidden layer represents a feature in the dataset. One node may represent an anomaly while another may represent a healthy number. These types of features are weighted by using the model's coefficients in the hidden layers and the results can be used to help predict where a datapoint represents, i.e. a healthy muscle number or atrophied. The constructed layer is called hidden because the users can't see the input entering a net and what sort of decisions comes out. It is difficult for people to understand how and why neural network processes data inside. These parameters are simply long vectors of numbers, readable by machines rather than people.

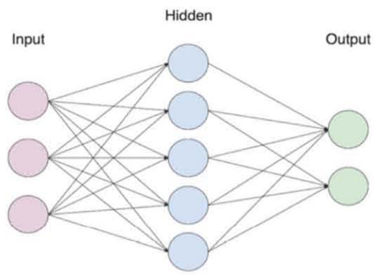

Figure 3. Schematic of a neural network [26]

V. Implementation

The implementation of *MusCare* can be divided into three parts: EMG-based microcontroller system, Android mobile application and anomaly detection.

A. *EMG-based Microcontroller System*

To demonstrate the monitoring processing for the muscles, we created a hardware prototype system with Arduino UNO and MyWare EMG sensor, which is used to collect muscle activities. In order to transmit the collected data from the hardware system to the Android mobile application, we used nRF8001 breakout, which supports BTLE 4.0, onto the breadboard to realize the Bluetooth connection. The layout of jumper wires between nRF8001 and UNO board is: (Figure 4)

- SPI Interface: SCK to PIN 13, MISO to PIN 12 and MOSI to PIN 11
- RCQ to PIN 10, RDY to PIN 2 and RST to PIN 9
- GND goes to GND rail and VIN goes to 5V rail.

Some technical challenges were faced, including getting the Bluetooth to work with Android, broadcast itself to nearby devices and transmit data from the EMG sensor to Android mobile application. For example, in terms of Bluetooth Low Energy (BTLE) support in Android, we found that the BluetoothAdapter's methods, including `.startLeScan()` and `.stopLeScan()` were deprecated after Android Lollipop (API 21) and BluetoothLeScanner was introduced instead. Corresponding changes are needed for supporting Bluetooth in Android 5.0+ versions.

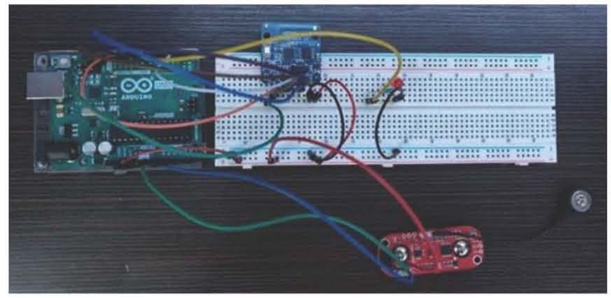

Figure 4. *MusCare* - Arduino UNO Board, nRF8001 Bluetooth breakout and MyoWare EMG sensor.

To visualize real-time data on the Android, we use MPAndroidChart [27], which is a Java library to support chart drawing, such as line-, bar-, pie-, radar-, etc. charts as well as scaling, dragging and animations. However, there was a technical challenge of configuring the transmission rate between the EMG sensor and the MPAndroidChart via the Bluetooth breakout. This issue was resolved by configuring the rate at which data was transmitted. (Figure 4)

```
void loop(){
  int currentVoltage = analogRead(A0); // store the incoming voltage
    BTLEserial.write(currentVoltage);
    delay(600);
```

Figure 4. Configuring the transmission rate of Bluetooth data in the microcontroller system.

B. *Android Mobile Application*

The UI of the mobile application is user-centered, simple and straightforward. Multiple paper prototypes were created and tested for the usability study. The final design was chosen based on simplicity and ease of use. (Figure 5)

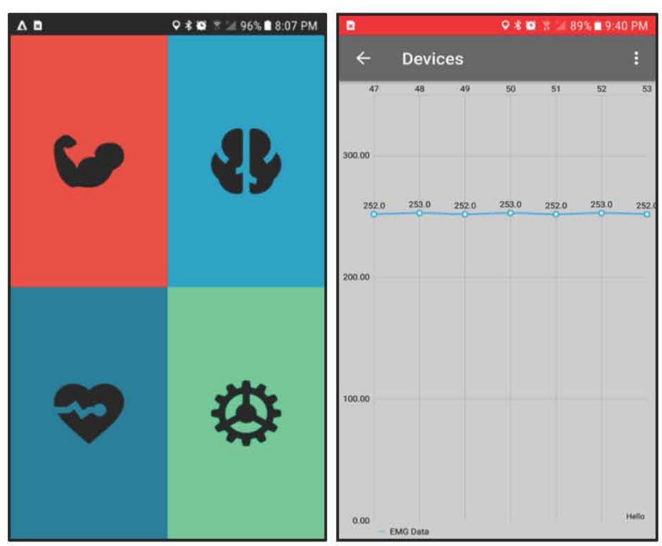

Figure 5. (Left) The main page of the mobile application; (Right) EMG data visualization

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The UI consists of 3 areas which have symbols indicating sections of different types of monitoring of the body. These sections include muscle (top-left), brain (top-right), and heart monitoring (bottom-left), illustrated in Figure 5 - (Left). The last section (bottom-right of Figure 5 - (Left)) is for managing the settings of the application. The muscle monitoring section is the one fully implemented at the time when the paper is written. When the section is clicked, a live graphing chart is shown, and data automatically starts being displayed on the screen (Figure 5 - (Right)). When the data is displayed on the screen, it is also added to an `ArrayList` and saved into a database which is referenced later for machine learning. In terms of the data storage, the mobile application uses SQLite, which is similar to SQL database and is a relational database supported in Android.

C. *Anomaly Detection*

To construct a neural network in Android, we used a Java-based deep learning library, DL4J [41], to create and train a neural network model on the device. The general requirement of using DL4J in Android mobile platform is: Android device or emulator that runs API level 21 or higher, 200MB+ of internal storage space, and Android studio 2.2 or newer. DL4J is an open source, distributed, deep learning library for the Java Virtual Machine (JVM). DL4J takes advantage of the latest distributed computing frameworks, including Apache Spark and Hadoop, to accelerate training.

By using DL4J, we built multiple layers by using signal strength of muscle data. The primitive algorithm detects anomalies that have low points in the graphed data. These low points mean less signal strength from the muscles monitored. With the numbers achieved from the device, a low point, or an anomaly defined in our case, would be in the range of 0 and 100. Based on current collected data, it can be summarized that prediction can be used to find potential risks. In addition, the collected data can be used to identify and predict a trend and alert the user that the muscle or muscles in question are at risk, but this information for what disease or ailment needs a further study.

VI. RESULTS

Based on the design, *MusCare* was created to demonstrate an idea of interactive design for muscle monitoring.

Firstly, a simple EMG-based microcontroller system was built. The system was built by using over-the-counter electronic components, including Arduino UNO, MyoWare EMG sensor, nRF8001 Bluetooth breakout, breadboard and jumper wires. The circuit layout is illustrated as Figure 4. Since it is a prototype system, it was not yet minimized to be a pocket size, but it is doable by using alternative hardware solutions, such as Arduino Micro, smaller Bluetooth breakout, etc.

Secondly, an easy-to-use mobile application was created for the users to interact with the EMG-based microcontroller system. The interface of this mobile application has four main sections. Three of them are reserved for getting vital signs from EMG-based microcontroller system, including electromyography (EMG), electroencephalogram (EEG) and electrocardiogram (ECG/EKG). The last section is used for managing the connections between the devices. Because of the time constraint, we currently only have the EMG section ready for use.

The EMG section of the application allows immediate graphing of the live data that is transmitted from the EMG-based microcontroller system. (Figure 5 - (Right)) While the Y-axis shows the voltage measured by the EMG sensor, the X-axis indicates time of the data in seconds. The transmission rate of the data is approximately one data point per second. When the sensor is placed onto the user, data points will fluctuate to different intensities on the Y-axis.

VII. DISCUSSIONS

There are a few challenges encountered during the design and implementation phases. Some of them were resolved, but some need further investigation. In this section, we would like to summarize some of them in this section.

A. *Real-time Data Visualization*

The EMG section of the Android mobile app visualizes live data received from EMG-based microcontroller system via Bluetooth. The values of the data present the strength of the muscle. This allows the users to monitor their muscle condition. The target users vary, ranging from a caretaker to a medical professional. Each of them might need different levels of information and this part can be extended for the future version.

In terms of displaying data, although MPAndroidChart was used in the project, this Java library has not been updated since 2017. As time goes on, SciChart would be a better solution. SciChart provides a high performance, real-time, feature-rich chart component built for developers of scientific, medical & engineering applications on Windows (WPF), and mobile (iOS/Android and Xamarin) [29]. The library includes all of the components MPAndroidChart has to offer and more, such as fast line charts for big data, medical monitoring applications (such as an ECG monitor), etc. Going forward, SciChart would be the next step to implement to further improve EMG data visualization.

B. *EMG sensor*

Some issues arose while we used the MyoWare EMG sensor, which was built to use with electrodes placed on the skin. This method is not as accurate and stable as the needle electrode method. Furthermore, loose attach and sweeting might affect the accuracy of the data. Such loss of accuracy of the data may include false anomalies or missing anomaly points. Surface EMG can provide a limited amount of data compared to needle-based EMG sensors. The benefits,

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however, include mobility and little-to-no pain compared to a needle being inside the muscle tissue.

C. Data Analysis and Storage

The current data analysis of the data involves using anomaly detection with DL4J. It is far from perfect. Current data storage for EMG data is onboard storage on the android which size is variable from device to device. For the future, depending on the size of data points that are needed to be collected, a stable database should be used, such as SQLite or Firebase.

D. Data Transmission Lost

When it comes to data transmission, the only issue that arose was the data input, which is too fast to be processed in the mobile application side. The data transmission was slowed down to accommodate the issue. At the moment, the rate for transmission for live graphing uses the default setting for the Bluetooth nRF8001 with a delay of 600 ms.

VIII. Conclusion and Future Work

Muscles are an important part of the human's bodies and monitoring their activities not only helps the users to be aware of their health, but it might also inference potential injuries. Muscular disorders are one type of muscular issues and we believe making muscle information transparent to the users can help in some diseases, such as Muscular Dystrophy (MD) and Muscle Atrophy (MA).

In this paper, we propose *MusCare*, which is a new mobile health platform that applies Internet of Things (IoT) and mobile engineering techniques to address the issue. The system uses a microcontroller-based system with an EMG sensor to collect muscle strengths and has an Android mobile application to visualize the real-time data, along with data analysis by the support of a machine learning library. To answer our research question, we found IoT and mobile engineering techniques can monitor muscle conditions. In addition, a machine learning algorithm has a potential to detect anomalies from EMG data in a mobile phone.

In conclusion, the proposed system, *MusCare*, is stable and able to transmit EMG data from a microcontroller-based system to the Android mobile application. The MyoWare EMG Sensor was able to be placed on certain regions to monitor muscle conditions. In the future, there are two directions of this research: (1) extend the system to support long-term monitoring that might cover 24 hours or longer, and (2) continue to improve the algorithm and the interaction design for anomalies detection from EMG data, such as adding the users' input into the system.

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