

EECS 351 Finalized Project Topic Report

For the final project in our EECS 351 class, we were originally tasked with coming up with two different ideas that would enable us to collect data and analyze it using Digital Signal Processing algorithms. The two ideas our group came up with were—a song suggester and electromyography (EMG) signal processing. We split this report into two parts, in which we share more details about how we completed the preliminary steps assigned to us for each project idea. At the end of this report, we present the project idea we chose to pursue and why we decided to do so.

Song Suggester

We envisioned that our song suggester would take in a song as its input, and output a similar song based on features we chose. Our first task was to determine what database we would use for our songs. We were provided with a Wikipedia link to a collection of online music databases. Going through the list, we eliminated different databases based on certain criteria, for example some databases did not have full free access. Ultimately, none of the databases found at this link, fit exactly what we were looking for, so we decided on one we found on our own—Free Music Archive. However, since downloading songs individually from the archive would take up a lot of time, we instead decided to rip songs from CDs we already had, thus creating our own database.

Our second task was to plot some of the songs, their FFT, and a spectrogram's output. Figure 1 below depicts our second tasks.

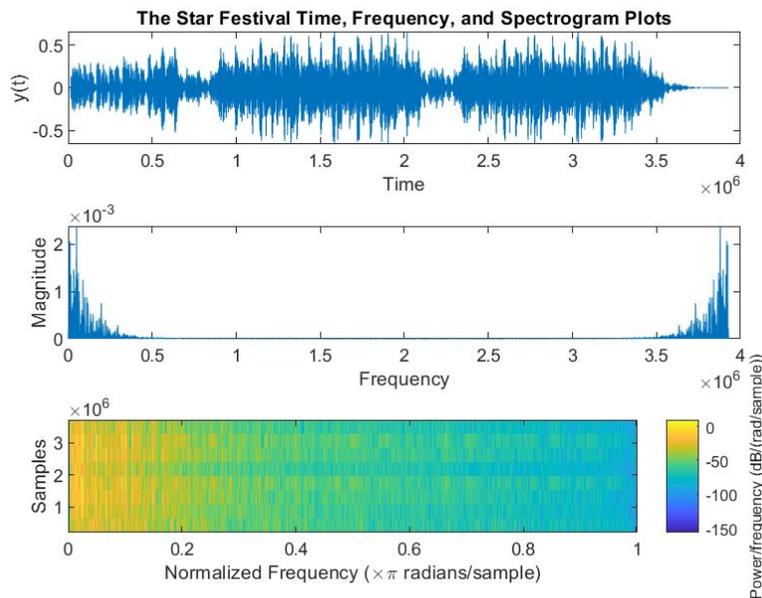


Figure 1. Time, frequency, and spectrogram plots of example song

The third task for the Song Suggester idea was to learn about the Matlab toolbox: MIRtoolbox for Humanities and Social Sciences. Here we went through the primer document which laid out how to use each function the toolbox had to offer. There are seven main categories of classification open through MIR classification. These branches of classification included Pitch, Tempo, Harmony, Timbre, Editorial, Textual, and Bibliographic. For the scope of our idea, the Editorial, Textual, and Bibliographic facets of MIR, are not feasible without additional metadata on the song. This leaves us using Pitch, Tempo, Harmony, and Timbre to extrapolate identifying features of songs. Going to the MIRtoolbox, there are many functions available to determine various components of each facet. Had we gone with this project idea, we would have spent more time understanding the parts of the toolbox that would have extracted the song information we wanted.

Finally, the fourth task was to learn about recommendation systems, since our song suggester was essentially that. For this task we had read the link provided which went in depth at all kinds of different recommendation systems. Recommender systems are what various programs such as Spotify and Netflix use in order to determine what a user might be interested in based on their interests/ratings. We were looking at using a content-based filtering approach as it would require more processing of the music itself rather than a user's interests. This broadened our horizons for what we initially thought possible for the project.

EMG Signal Processing

The first task we were given for our EMG idea was to acquire sources of data. We took a two-step approach to fulfill this requirement: collecting data ourselves with an EMG sensor and looking for online datasets. Because one of our team members (Tyler) had developed a custom-built EMG sensor for another engineering class, our team had access to data that we can collect ourselves. The data collected by the custom-built EMG sensor was first passed through a bandpass and a notch filter, followed by a root mean square operation, then lastly passed through a low-pass filter (which was designed in MATLAB using the FDA tool) in sequential order. The following lists show the filter specifications for the bandpass, notch, and low-pass filters applied to the data.

- Band Pass and Notch Filtering:
 - 60 Hz Notch Filter
 - 50Hz - 150Hz Bandpass Filter
 - 1000 samples/second
- Low-Pass Filter:
 - 48000 Hz Sampling Frequency
 - 9600 Hz Passband
 - 12000 Hz Stopband

We then used MATLAB to plot the data in the time domain and frequency domain, and also plotted a spectrogram as seen in Figure 2. While the bandpass and notch filters were carefully applied to the raw sensor output to provide meaningful data (by Tyler and her bio-engineering colleagues), the low-pass filter was designed and applied to the data to demonstrate what types of

filtering our team would do as one of the later steps in our project. Consequently, the output of the low-pass filter shows a phase shifting of the RMS Bicep Flexion Data as seen in Figure 2, which is an undesirable behavior that our team will correct as the project progresses.

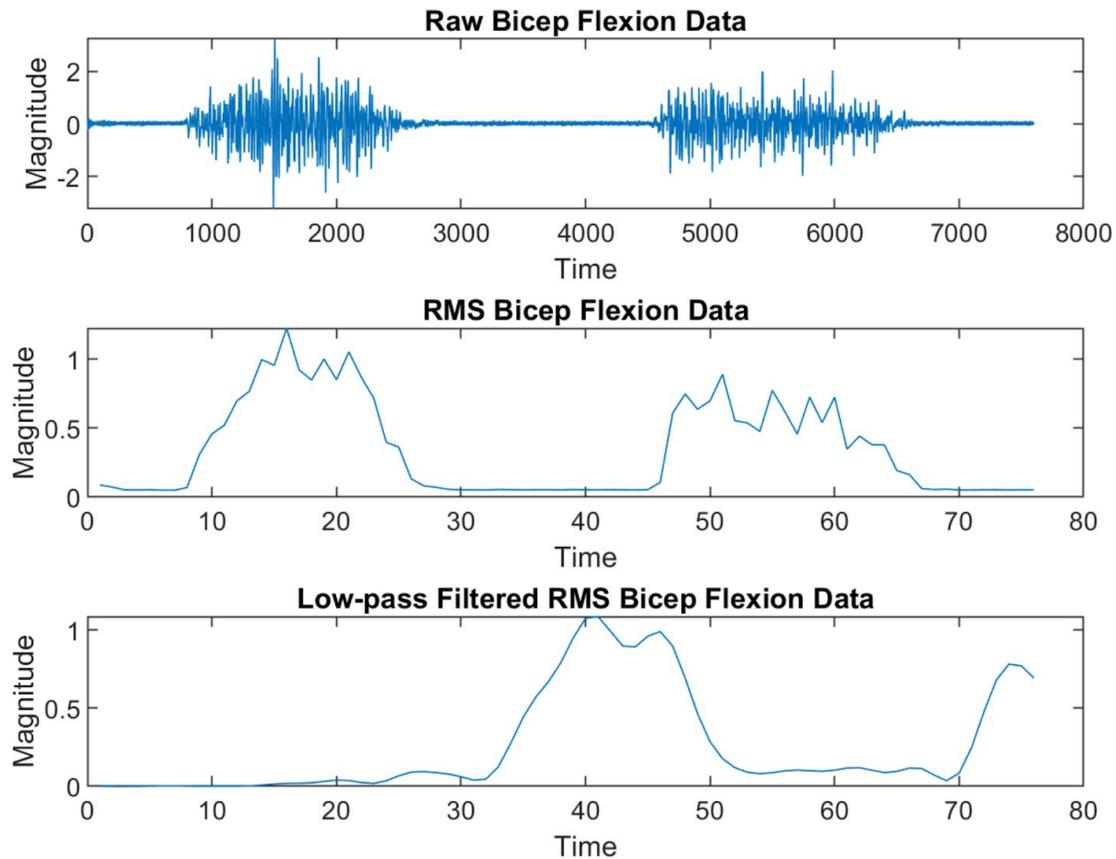


Figure 2. EMG data taken from a custom made EMG with bandpass and notch Filter (top), root mean square of EMG data (middle), and root mean square sent through a low-pass filter (bottom). The output of the low-pass filter is phase-shifted, which is an undesirable result, but the oscillations near the maximum magnitudes of the plot were nearly eliminated as expected.

In addition to the data collected with the custom-built EMG sensor, we also looked for online datasets. In particular, one dataset that we found was collected by Lobov et. al., which consisted of 36 subjects who were instructed to perform 7 different gestures with their hands for a total of 2 trials each [1]. The data was collected with a MYO Thalmic Bracelet, which produces 8 channels of data [1]. This dataset was one of the more relevant and useful results of our dataset search because two of the gestures (both of which are associated with wrist motions) could be replicated in person by Tyler and her colleagues using their custom-built EMG sensor. Furthermore, the number of subjects and trials provided in this dataset would be a great foundation for developing a classifier (see “Next Steps” section). This online dataset was used to complete the second task for the EMG signal processing project.

Our second task was to plot a comparable portion of another patient's data and analyze the similarities and differences between the two different datasets. Figure 3 and Figure 4 below provide the time and frequency comparison of EMG data sets from two different individuals.

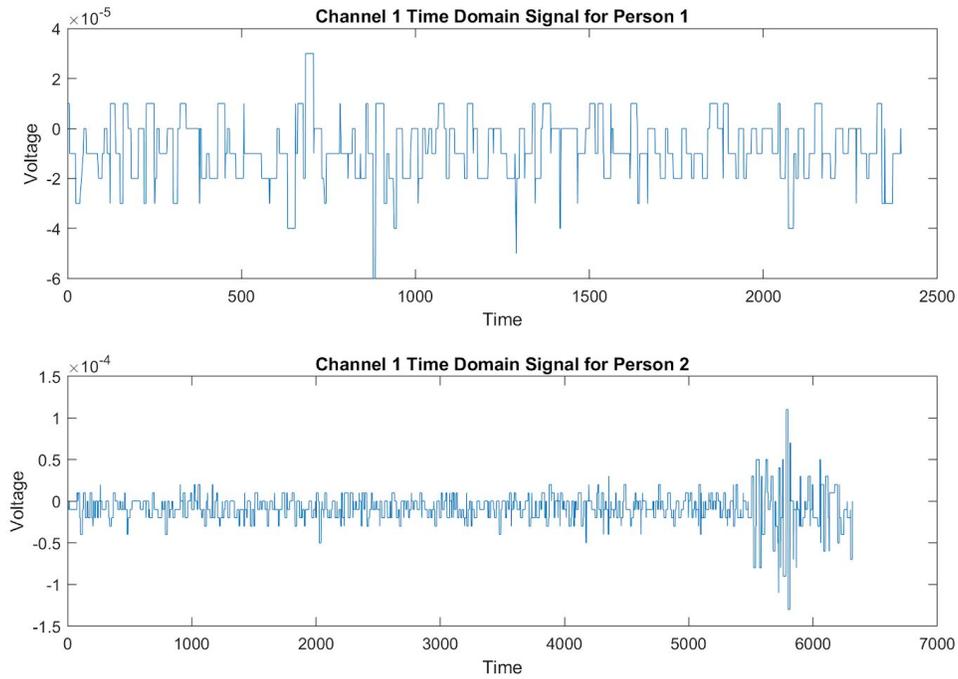


Figure 3. Time domain comparison of two EMG datasets

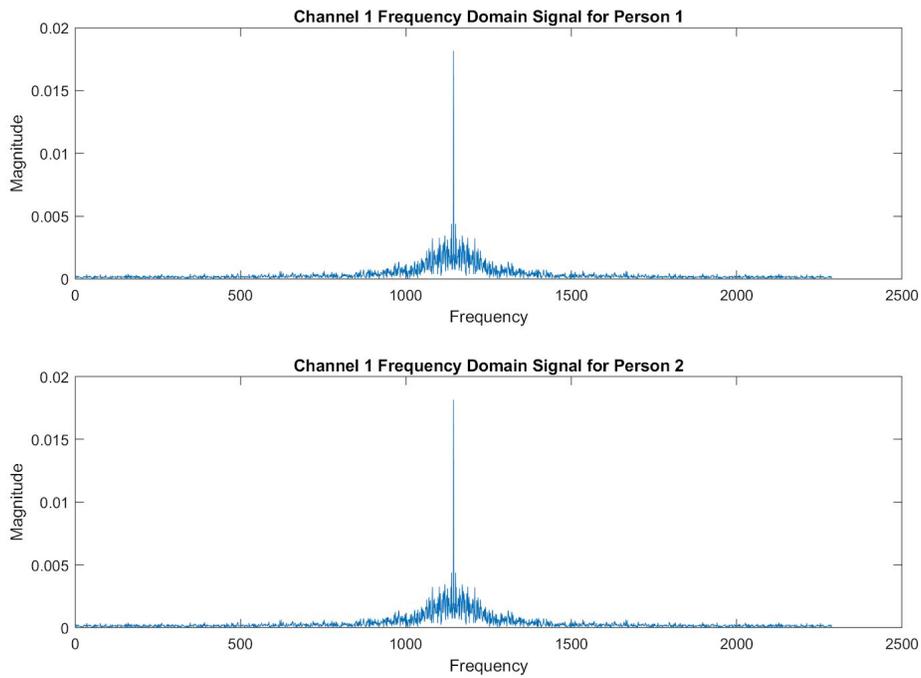


Figure 4. Frequency domain comparison of two EMG datasets

The first of these datasets has a noticeably larger amount of data. This made direct time domain comparison difficult. As such, we will need to compare different dataset lengths to find which are the most comparable. When looking at Figure 4 however, the signals look significantly more similar, both having a peak around 1100Hz.

For our third task we looked at different ways that EMGs are used in the medical field today. In our research, we found that EMGs have multiple uses within the medical field including: disorder diagnosis, muscle therapy, prosthesis, and remote surgery. EMG data can be used to diagnose different muscle related diseases. This is done by taking the EMG data (when the muscle is active and resting) of a patient on a particular muscle group and comparing it to datasets of normal muscle behavior and abnormal muscle behavior. This test can help determine if the patient is suffering from disorders such as[2]:

- Carpal tunnel syndrome
- Herniated disc
- Muscular dystrophy
- Amyotrophic lateral sclerosis (ALS)

EMGs can also be used to treat chronic headaches, anxiety, and retrain muscles. This is done using biofeedback therapy [3]. In biofeedback therapy, EMGs are used to show the patient, and the doctor treating them, what different muscles are doing while they are suffering from their symptoms. The patient and doctor then go through different muscle relaxation exercises to try to determine possible remedies for the problem.

EMG data has also been used to create prosthetics that are controlled by the remaining muscles of amputees[4]. The prosthetics are often for the arm and hand allowing the amputee more dexterity than with traditional prosthesis. Similarly, upper limb EMG data has also been used to conduct remote surgeries[5]. Heart surgery is now possible when doctor and patient are 20 miles away.

Outside of the medical field, EMGs have applications in entertainment and learning settings by combining them with virtual reality (VR). More specifically, EMG signal processing can be an alternative sensor scheme for VR controllers. Some of the well-known VR gaming sets, such as the Cosmos Elite, Oculus Rift S, or the Playstation VR, make use of handheld controllers that include a variety of sensor fusion packages (many of them utilize IMUs) to mainly display wrist motions [6-8]. These controllers lack the ability to display finger articulations (because the user has to grasp the controller handle), as well as the ability to display motions of limbs upstream from the wrist (elbow, shoulder, etc.)

On the other hand, haptic glove technology can provide the missing capabilities that gaming set VR controllers cannot. These gloves, such as the [Haptx](#), [VRgluv](#), and more recently, the [Teslasuit Glove](#), provide not only the appropriate sensor fusion scheme and hardware interface for tracking finger articulations, but also enable tactile feedback that allows users to “feel” a virtual object [9-11]. Aside from the obvious applications in gaming (as this technology pushes the limits of how realistic a game can be), these haptic gloves are also in demand for professional training and medical rehabilitation [11]. However, these gloves are not currently suitable for

widespread personal enjoyment because most of these technologies are targeted towards businesses and therefore are expensive to purchase (for example, Teslasuit Glove creators are planning a market price of \$5000 for the entire VR package) [11]. The number of sensors needed to record motion - most likely inertial measurement unit (IMU) or some other sensor that can track the motion of one joint with respect to another, or may include advanced software techniques to infer joint kinematics based on a fewer number of sensors - as well as the integration of actuators to provide the tactile sensation, could be some of the factors that drive the market price of haptic gloves. Furthermore, these haptic gloves do not provide motion display of any limbs upstream from the wrist, similar to the gaming VR controllers; incorporating such motions (as well as lower limb motions) would require a full body haptic suit.

Given the two extremes of VR hand controllers, an EMG signal-based VR controller can be a more affordable technology that provide motion articulations for not just the hand, but for the rest of the body as well (note that suits like the Tesla Suit may have in-built EMG sensors, but most likely these sensors are used to monitor the health and muscle performance of the users, not as the main driving sensor scheme for capturing motion input). EMG sensors do not cost very much to buy or build (~\$40 from Sparkfun as well as a custom built EMG created from a differential amplifier using LM741 OP Amps and AD620 Op Amps), and electrode pads can increase the number of data collection locations without significant financial overhead (~\$8 for a pack of 10 electrodes from Sparkfun).

The ability of EMG sensors to pick up multiple muscle signals can be leveraged with signal processing tools to reduce the total number of sensors needed to measure multiple limb movements. While IMUs may provide more accurate and localized motion data than EMG sensors, their functionalities may not be efficiently utilized because of the biomechanical constraints of the human body (for example, a 3-axis IMU is unnecessary to track the motion of finger flexion, which only consists of single-axis rotations). Furthermore, IMU measurements are localized to a single joint, which necessitates the inclusion of more sensors to accommodate the number of joints. However, a single EMG-based sensor, such as the Myo Bracelet, can collect data on finger articulation as well as wrist movements [1].

However, several signal processing challenges must be overcome in order to provide EMG data in a useful form. Signals from muscles that are close together must be separated. Muscle movement must be classified to determine what bodily movements will result. Noise must also be removed from the signal. Most importantly, the data itself must be converted to RMS or another form in order to be readable by other devices as the actual EMG data in time domain looks very similar to noise.

The fourth task we were given was to determine what further analysis we would like to perform using the EMG data. We decided on translating the EMG signals into a synchronous display of the corresponding moving limbs. Our final deliverable will be a demo showing the use of EMG signals as a direct input to generate corresponding graphic displays as an example of a VR biofeedback therapy system. Doing so would leverage the usefulness of EMG data in capturing user motions for input into VR systems, as well as reflecting the user's health conditions. In order to develop this deliverable, we will use three different software tools: CAD (Computer Aided Design), Simulink, and Simscape.

Below, we have demonstrated how we will use each of these tools. We will use CAD to model the moving limbs. This can be seen in Figure 5, which is a rudimentary representation of the upper limb (shoulder, bicep, elbow, and forearm).

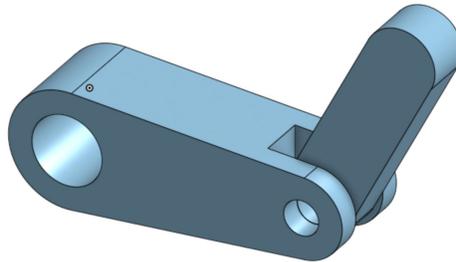


Figure 5. Simple CAD model for bicep

We will use Simulink to create a block diagram of the system that will be used by Simscape to simulate motion of the CAD model we have created. This can be seen in Figure 6 below.

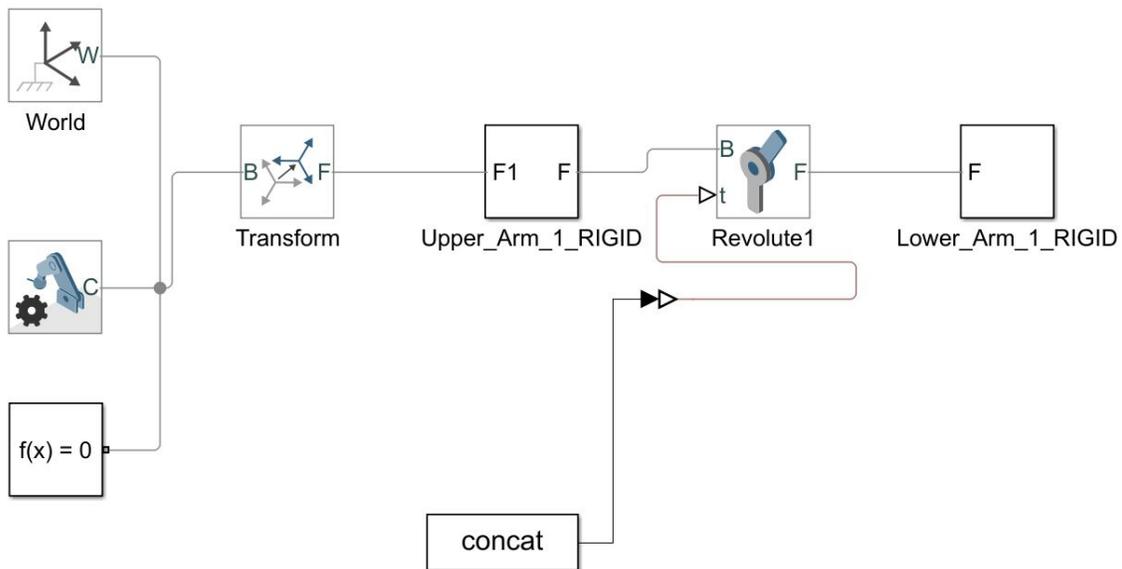


Figure 6. Simulink block diagram of transfer function

The Simscape library will then allow us to take a filtered form of the EMG signals that is sent through the Simulink block diagram and use the output to control the CAD model movement. The Simscape Mechanics Explorer, which is used to show CAD renderings and their motions, can be seen in Figure 7 below.

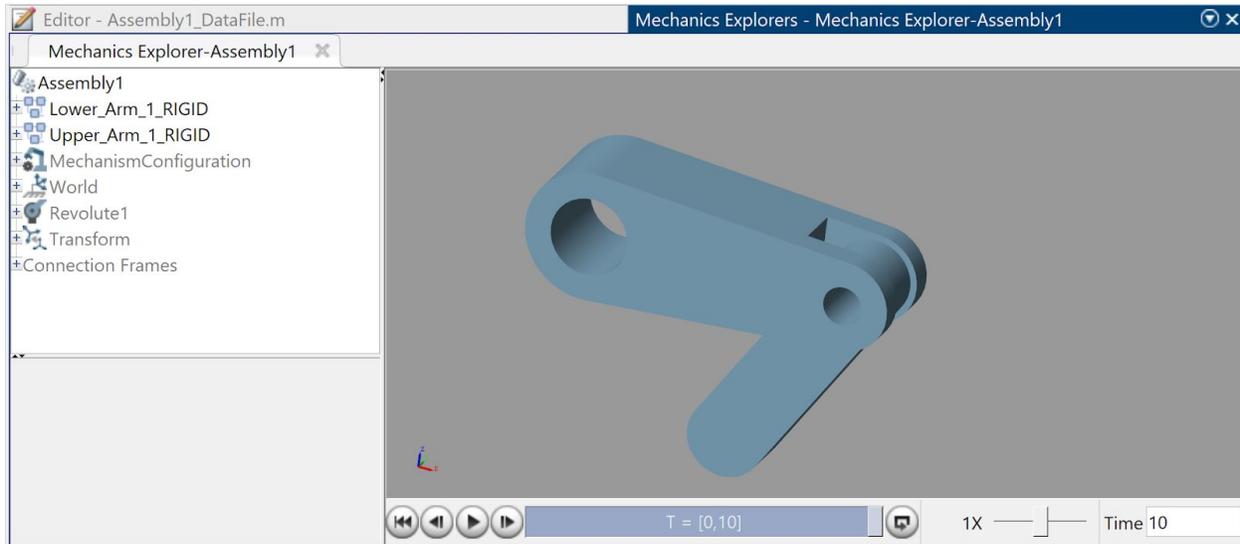


Figure 7. Simscape system for model control

Finally, we had to decide which project idea we were going to pursue and work on for the remainder of the semester. Ultimately, we decided to work on the EMG signal processing project to demonstrate that signals can be used as real-time inputs for VR systems in the context of biofeedback therapy. Though we were very excited about the song suggester idea, we felt that there were many constraints on what we could achieve within the given time period. For example, we would likely have had to work with a relatively small database of songs, which would be a significant compromise from our original idea of being able to provide users with unique and new song suggestions based on their preferences. We're really excited to be working with the EMG data because it has so many interesting applications in the medical and entertainment fields.

Next Steps

In order to get the EMG data that we have collected and found through other resources into a usable form, the signal will need significant filtering and data interpretation. The RMS signal currently being used to run simscape is a very rough image of actual muscle movement. The team will be looking into several filtering methods including the Daubechies Wavelet filter [12]. The goal is to smooth the data to produce more fluid movements from the simulation.

In addition to processing the data, the team aims to determine physical movements based on multiple EMG signals. This can be done by determining the median frequency using the FFT to find the power spectrum [12]. Higher median frequencies correspond to stronger muscle contractions. Using this information to compare the different muscle contractions and strengths needed for a single movement, the team hopes to classify what movements were intended by the user to monitor their health conditions and also use as error compensation for the VR rendering of the limb.

References

- [1] Lobov S., Krilova N., Kastalskiy I., Kazantsev V., Makarov VA., “Latent Factors Limiting the Performance of sEMG-Interfaces,” in *Sensors*, Apr. 2018. [Online]. Available: <https://pubmed.ncbi.nlm.nih.gov/29642410/>
- [2] “Electromyography (EMG) and Nerve Conduction Studies: MedlinePlus Medical Test,” [medlineplus.gov. https://medlineplus.gov/lab-tests/electromyography-emg-and-nerve-conduction-studies/](https://medlineplus.gov/lab-tests/electromyography-emg-and-nerve-conduction-studies/). (accessed Nov. 01, 2020).
- [3] “How is electromyogram (EMG) used in biofeedback therapy?,” [webmd.com. http://www.webmd.com/a-to-z-guides/qa/how-is-electromyogram-emg-used-in-biofeedback-therapy](http://www.webmd.com/a-to-z-guides/qa/how-is-electromyogram-emg-used-in-biofeedback-therapy). (accessed Nov. 01, 2020).
- [4] “Myoelectric Prosthetics.” [ottobock.com. www.ottobock.com/prosthetics/upper-limb-prosthetics/solution-overview/myoelectric-prosthetics/](http://www.ottobock.com/prosthetics/upper-limb-prosthetics/solution-overview/myoelectric-prosthetics/). (accessed Nov. 01, 2020)
- [5]Leman, J. “Robot Helps Perform First Long-Distance Heart Surgery,” [popularmechanics.com. www.popularmechanics.com/technology/robots/a28941179/robot-performs-first-long-distance-heart-surgery/](http://www.popularmechanics.com/technology/robots/a28941179/robot-performs-first-long-distance-heart-surgery/). (accessed Nov. 01, 2020).
- [6] “Cosmos Elite.” [vive.com. https://www.vive.com/us/product/vive-cosmos-elite/overview/](https://www.vive.com/us/product/vive-cosmos-elite/overview/). (accessed Nov. 04, 2020).
- [7] “Oculus Rift S.” [oculus.com. https://www.oculus.com/rift-s/](https://www.oculus.com/rift-s/). (accessed Nov. 04, 2020).
- [8] “PlayStation VR.” [playstation.com. https://www.playstation.com/en-us/explore/playstation-vr/](https://www.playstation.com/en-us/explore/playstation-vr/). (accessed Nov. 04, 2020).
- [9] “HaptX Gloves Development Kit.” [haptx.com. https://haptx.com/](https://haptx.com/). (accessed Nov. 04, 2020).
- [10] “VRgluv Enterprise.” [vrgluv.com. https://www.vrgluv.com/enterprise](https://www.vrgluv.com/enterprise). (accessed Nov. 04, 2020).
- [11] Robertson, A. “Teslasuit’s new VR gloves let you feel virtual objects and track your pulse.” [theverge.com. https://www.theverge.com/2019/12/26/21037855/teslasuit-glove-vr-haptic-feedback-glove-announce-pricing-release-date-ces-2020](https://www.theverge.com/2019/12/26/21037855/teslasuit-glove-vr-haptic-feedback-glove-announce-pricing-release-date-ces-2020) (accessed Nov. 04, 2020).
- [12] Reaz, M., Hussain, M., & Mohd-Yasin, F. (2006). *EMG analysis using wavelet functions to determine muscle contraction* [Scholarly project]. In *Griffith Research Online*. Retrieved November 09, 2020, from https://research-repository.griffith.edu.au/bitstream/handle/10072/46713/72849_1.pdf?sequence=1&isAllowed=y