Final Report: Dysphagia Device

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Background and Significance

Dysphagia is the medical term for swallowing difficulties. This medical condition is most prevalent in older people[2]. Dysphagia can be caused by multiple sources, primarily originating from physical structures in the esophagus preventing food from effectively being swallowed, and neurological issues causing inefficient swallowing[3].

Physical complications of the esophagus primarily arise due to cancer of the esophagus, scarring of the esophagus often caused by esophageal reflux, or a stricture in the esophagus[3]. These conditions result in an abnormal form or tightening of the esophagus, making it difficult for the patient to swallow.

Neurological Complications arise from neurological disorders, neurodegenerative disorders, or damage in the brain, spinal cord, or esophagus causing inefficient muscle contractions of the esophagus. Conditions related to this are traumatic injuries to the brain or spinal cord, diffuse spasms, stroke, multiple sclerosis, and Parkinson's Disease[1]. These conditions damage the neural connections between the brain and esophagus, resulting in inefficient muscle movement of the esophagus while swallowing.

Dysphagia can result in severe discomfort or inability to swallow, often resulting in malnutrition and dehydration. Aspiration pneumonia is another complication associated with dysphagia. The incorrect muscle contractions of the esophagus can result in food or water entering the lungs. The bacteria in the food or water can result in pneumonia[1].

Currently, dysphagia is diagnosed primarily using barium x-rays, endoscopies, and manometries[5]. Barium x-rays require that the patients' esophagus is coated with a barium solution or that the patient swallow barium coated items while a fluoroscope is used to study the shape and muscular activity of the esophagus[6]. This process exposes the patient to harmful x-rays for the duration of the barium x-ray study. This method is also left up to the doctor's visual

interpretation of the x-ray results to determine the severity and causes of dysphagia, which can be subject to human error.

Dysphagia can also be diagnosed using endoscopies and manometries[5]. Endoscopies allow the doctor to perform a visual examination of the patient's esophagus. This method is an invasive procedure. In addition, using this method, the doctor can only see physical issues with the esophagus such as a narrowing, tumor, or inflammation. This method is ineffective for determining a neurological cause due to its inability to study the muscle contractions themselves. Manometry is the insertion of a tube with a pressure recorder to measure the esophagus muscle contraction pressure, speed, and pattern to determine if the cause of the dysphagia is from muscle contraction complications[7]. This method is also an invasive procedure. The endoscopy and manometry can be used together to look for neurological and physical causes, but this requires two invasive procedures both of which could be subject to human error.

The device presented in this paper uses two electromyography (EMG) sensors and a microphone sensor to collect muscle and noise data from the patient's esophagus while they are swallowing. The current work is focused on fabricating more devices which will allow for a larger set of labelled and filtered patient data to be collected. The end goal of this project is to use the labelled patient data to train a convolutional neural network (CNN). The CNN will then be used to quantitatively and qualitatively diagnose the severity of patients' dysphagia, and give insight into the underlying symptoms and preventive measures. This will provide an alternative, noninvasive and nonharmful method to accurately diagnose patients and give doctors useful insight into their condition.

Research Methods

The dysphagia device is designed to rest on the patient's neck, monitoring their swallowing behavior by recording muscle movements and noises from inside the esophagus. The working principle behind this device is that initially it will be used to collect labelled EMG and microphone data from patients that are known to have or not have dysphagia. This data will then be filtered and used to train a convolutional neural network (CNN). The final goal is for the device to be used on patients with an unknown swallowing condition to actively monitor their muscle activity and noise while they swallow. The trained CNN can then be used to quantitatively and qualitatively diagnose the severity of a patient's symptoms and diagnose underlying symptoms.

The full device, as shown in Figure 1, consists of a main circuit board, two EMG sensors, and a microphone. The EMG sensors rest on the upper and lower parts of the esophagus. These sensors monitor and give insight to the muscle activity in the upper and lower portions of the esophagus. The microphone rests over the center of the neck, and records noises of the food passing through. This gives insight into whether the food or liquid is passing through and if the swallowing was effective up to that point.

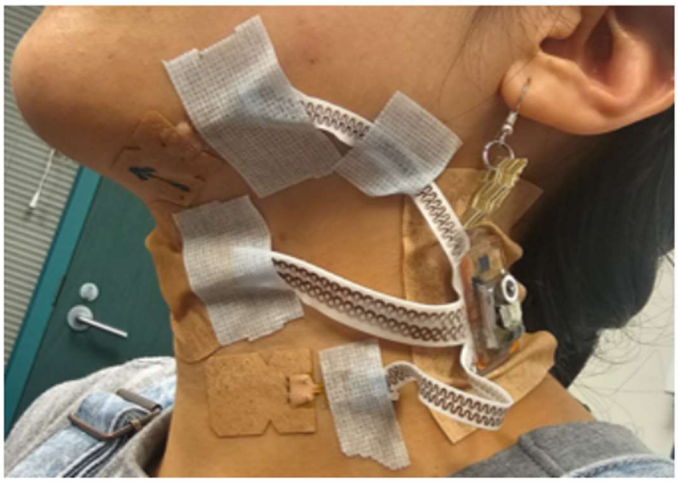

Figure 1: Dysphagia Device on Patient

The components of this device consists of a printed circuit board (PCB), battery, eco-flex, electrodes, EMG patches, microphone, and fabric patches.

The PCB is assembled using surface mount soldering. The general fabrication procedure for this is to solder on the integrated circuits and run them through a process of pressing down the chip, soldering and desoldering where necessary, while checking for any shorts or detachments of the PCB.

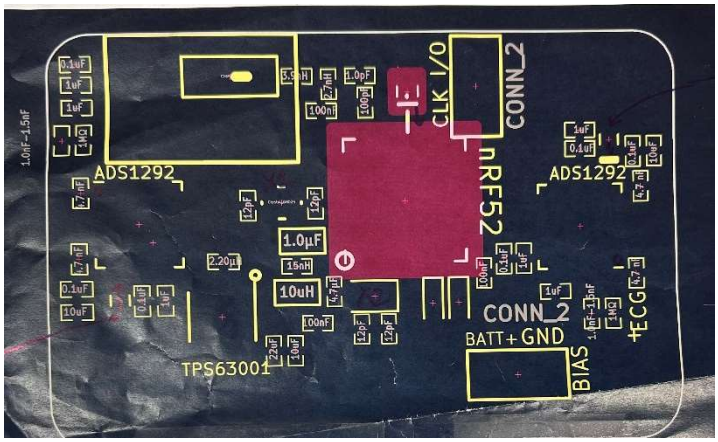

Figure 2: Circuit Diagram of Main PCB Component

The passive components are then attached, and the circuit is flashed to ensure it functions properly. Figure 2 shows the circuit diagram on the main PCB component, and Figure 3 shows the circuit diagram for the microphone component.

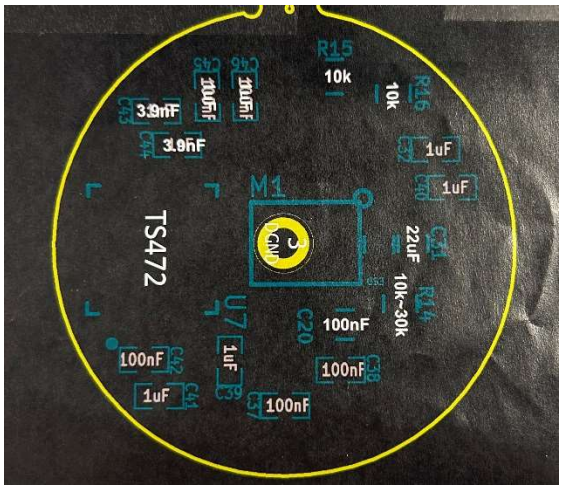

Figure 3: Circuit Diagram of Microphone Component

Eco flex is then applied to the flexible wires that extend from the central PCB to the EMGs and microphone. The geometry of these wires allows for them to easily extend, and the eco-flex provides an elastic force to ensure that the wires return to their natural shape after being extended.

The central PCB component is attached to a re-usable fabric patch using eco-flex. The grounding electrode is then attached to the bottom of the fabric patch using soluble tape. The soluble tape is then dissolved away, and the electrode is cleaned and dried. A thin copper wire is then attached to the electrode

Figure 4: Ground Electrode

using silver paint. A small incision is made in the fabric patch, and the grounding wire from the main PCB is pushed through and soldered to the thin copper wire, thereby attaching the ground electrode to the main PCB component as shown in Figure 4.

The rechargeable battery uses a switch and magnetic charging plate to allow for the battery to be recharged. The switch, magnetic charging plate, and positive and negative wires from the battery are all soldered together as shown in Figure 5. The switch allows for the battery to alternative between states of being on and charging.

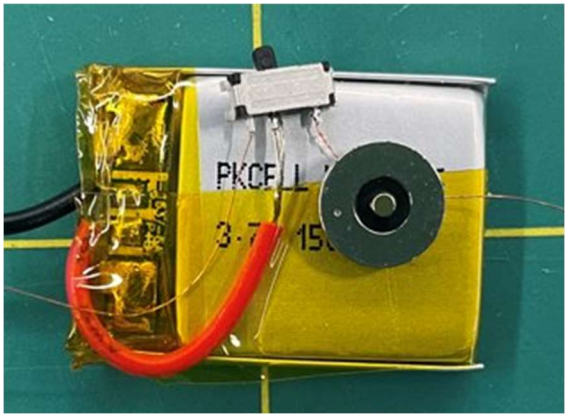

Figure 5: Rechargeable Battery Component

The rechargeable battery is then epoxied on top the main PCB component, providing protection to the main PCB passive components, while being in a convenient location and allowing for a compact design for the device. The positive and negative terminals of the rechargeable battery are then soldered to their respective battery ports of the PCB to supply power to the device.

The EMG electrodes are fabricated with re-usable fabric patches, gold electrodes, and copper wires as shown in Figure 6. The general process for fabricating the electrode is to first place the gold electrode, which is attached to soluble tape, onto the sticky side of the fabric patch and then cover it with water. The tape will dissolve, leaving behind the electrode attached to the fabric patch. Wash off the soluble tape residue and use a foam brush to gently clean the electrode. Place the fabric patch and electrode over a hot plate to dry it. Then, attach the small copper wires to each of the electrodes using silver paint, and allow it to dry.

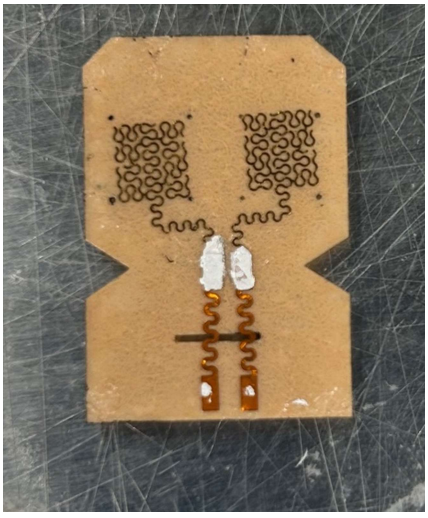

Figure 6: EMG Electrode

The EMG electrode patches are then soldered onto the copper wires extending from the central PCB. The microphone component is placed on top of, and covered in, eco-flex to ensure close, stable, and comfortable adhesion to the skin's surface. The main PCB component and rechargeable battery are then covered in eco flex.

The full device, as shown in Figure 7, is then placed on the patient's neck. One EMG is placed on the upper esophagus, the microphone is placed over the middle of the throat, and the second EMG is placed over the lower part of the neck. The central component of the device harboring the main PCB and rechargeable battery is attached to the side of the patient’s neck, away from the sensors.

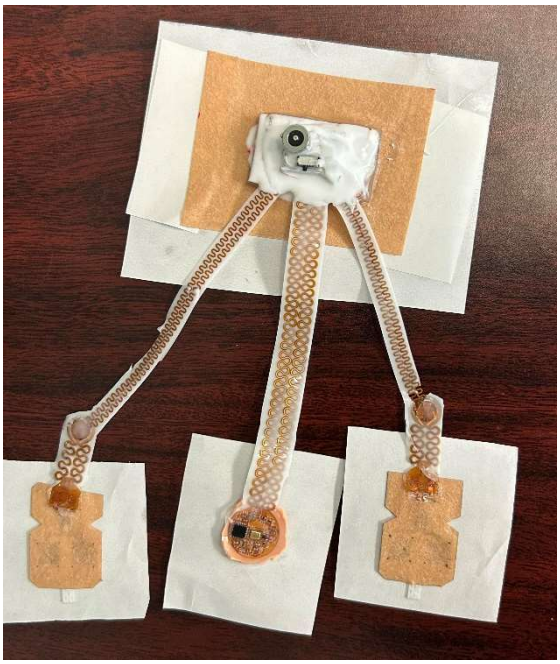

Figure 7: Full Device

The two EMG sensors record muscle data at a rate of 250 Hz. The EMG data is then edited so that only data specific time domain where both the EMG and Microphone data are being collected simultaneously is analyzed. This allows for the two different sets of data to be cross analyzed more easily. The raw EMG data is also DC shifted and consequently is run through a high pass filter of 20 Hz to normalize this shift.

The microphone data is collected at a rate of 2000 Hz. The microphone data is also filtered like the EMG data so that both the EMG and Microphone data can be aligned on the same time domain and be effectively compared. The microphone data is further processed using a bandpass filter, graphic equalizer, and fast Fourier transform.

First, the bandpass filter is applied so that only data in the frequency domain between 20 Hz and 900 Hz remains. Then, the noise data is graphically equalized three times. This allows

for frequencies near 567 Hz that are related to swallowing to be boosted, increasing the visibility of the swallowing noise, and separating it from the background noise. A fast Fourier transform is then applied to the data which is effective at removing much of the underlying background noise, creating a more defined waveform with discrete jumps in amplitude when food or liquid is passing through that portion of the esophagus.

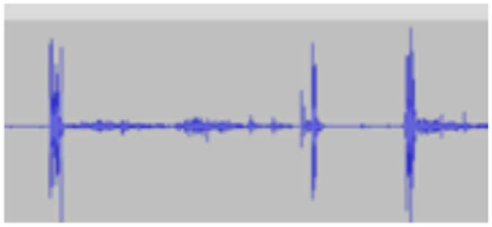

Figure 8: Unfiltered Microphone Data

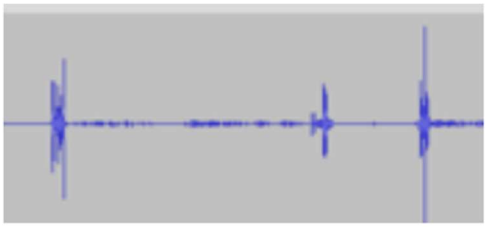

Figure 9: Filtered Microphone Data

The original noise in Figure 8 was run through this process. As shown in Figure 9, much of the noise has been eliminated and the lines defining swallowing are more well defined. This process creates more defined sound waves indicating specifically when someone is swallowing, which is necessary for accurately training the CNN.

Figure 10 is a picture of the EMG data from the upper EMG sensor and Figure 11 is a picture of the EMG data from the lower EMG sensor from the same patient that the microphone data in Figure 9 was gathered from. Images 9, 10, and 11 are samples taken from the same patient over the same time interval and demonstrate a very insightful concept of what the working principle behind this device is.

Figure 10: Upper EMG Data

Figure 11: Lower EMG Data

The EMG resting on the upper esophagus, as shown in Figure 10, shows many high amplitude, repetitive movements. This is indicative of the early stages of swallowing, where the patient is producing the initial muscle activity to get the food started down the esophagus. The microphone data shown in Figure 9 shows the noise when the patient is somewhat successful in

swallowing, and some amount of food or liquid passes through that portion of the esophagus. Figure 11 shows the EMG from the lower esophagus. This shows the muscle activity in the final stages of swallowing. If the patient is effectively swallowing, there will be activity in the lower EMG sensor indicating this.

Using this data produced by the EMGs and Microphone, the process of someone swallowing can be analyzed. The analysis of this data can lead to conclusions about if a patient has dysphagia, how severe their dysphagia is, and what it could be caused by. This device seeks to automate and improve this process through using a trained machine learning algorithm.

The current work is focused on developing more of these dysphagia devices to be distributed to different hospitals. These devices are being used on patients with and without dysphagia to generate a labelled set of EMG and Microphone data corresponding to patients with and without the condition. This data is then being filtered using the data processing procedure described previously to create a set of filtered, labelled data that will then be used to train the CNN.

Then the goal is to have a device that can be used on an undiagnosed patient. By actively collecting EMG and microphone data from the patient while they are swallowing, the goal is that a trained CNN will be able to interpret the EMG and microphone data to determine if the patient has dysphagia, how severe the dysphagia is, and what the underlying cause could be.

Discussion

People with dysphagia have difficulty swallowing originating from physical issues with the esophagus such as strictures or tumors, or muscle contraction issues originating from neurological problems. This dysphagia device is based on the working principle that dysphagia, and its underlying causes, can be identified by analyzing the muscle contractions of the esophagus and the noises that are produced when the patient swallows.

This device uses two EMG sensors and a microphone. One EMG is placed on the upper esophagus and the other is placed on the lower esophagus to analyze the muscle movements in the upper and lower esophagus respectively. The microphone is placed over the center of the throat to monitor swallowing noises.

The current focus of this research is to create more devices that can be distributed to more hospitals and patients. The goal is to use this device on several individuals with and without dysphagia to create a labelled set of data that can be used to train a machine learning algorithm. Another part of the current focus is to process and filter this data while we are receiving it so that there is a labelled, filtered data set that can be used to optimally train a CNN.

Using this dysphagia device with a trained CNN yields the final result of a device that actively monitors a patient's swallowing process and diagnoses the patient. The CNN will monitor the EMG and Microphone signal coming from a patient and use this to accurately diagnose them with dysphagia, the severity of their dysphagia, and potential underlying causes.

This semester I have been working on fabricating more of these devices and processing the data. At the first half the semester, the focus was to develop the PCB components. Over the course of this semester, I completed 12 successful PCB components. Another component of my work that carried over the entire course of the semester was processing the incoming patient data using the procedure described in ‘Research Methods’. I successfully processed 43 sets of

patient EMG and Microphone data, which will later be used to train a CNN. Finally, in the second half of this semester, I began focusing on fabrication steps, including fabrication of the electrodes, eco flexing of the device, fabrication of the rechargeable battery, and the entire assembly of the device. Over the course of the semester, I was able to make 5 complete devices. The next steps are to continue the process of fabricating more dysphagia devices which can be distributed to a larger group of patients. The incoming raw patient data will continue to be processed until a large enough training set has been produced for training the CNN. The final step is the train and test the CNN for accuracy in diagnosing patients.

Conclusion

This dysphagia device is designed to monitor EMG and microphone data from the esophagus with the goal of using it to diagnose patients with dysphagia. The device itself consists of a flexible PCB, a rechargeable battery, eco flex, fabric patches, two EMG sensors, and one microphone sensor.

One EMG sensor is placed on the upper esophagus, the microphone is placed in the center of the esophagus, and the second EMG is placed on the lower esophagus. The device collects data regarding muscle movements and noise of the esophagus when the patient is swallowing. Currently, these devices are being used to record patient EMG and microphone data. This labelled data is then processed and labelled to train a CNN. Using a trained CNN, the device is intended to diagnose the patient with dysphagia and give insight into the severity and underlying causes.

At the beginning of this semester, my focus was on fabricating PCB components. Over the course of the semester, I was able to complete 12 PCB components. Over the course of the entire semester, I focused on processing patient EMG and Microphone data that we were receiving. I processed a total of 43 sets of EMG and Mic data over the course of the semester. Lastly, towards the end of the semester, I focused on the full fabrication of the device. I was able to produce a total of five complete devices.

The goal of this research is to use a trained CNN with this device to actively monitor patient's esophagus muscle movements and noises to diagnose them with dysphagia, in addition to give doctors insight into the severity of their condition and potential underlying causes.

Future work will be focused on producing more devices to collect more raw patient data. In addition, the incoming patient EMG and Mic data will continue to be processed until a large

enough training set is produced to train the CNN. The CNN will then be tested to assess the devices accuracy in diagnosis dysphagia, its severity, and underlying causes.

Work Cited

1. Dysphagia.https://www.mayoclinic.org/diseases-conditions/dysphagia/symptoms-causes/syc-20372028 (accessed 2023-06-26).

2. Dysphagia. https://www.nidcd.nih.gov/health/dysphagia (accessed 2023-06-26).

3. Phillips, M. M. Difficulty Swallowing (Dysphagia). https://www.pennmedicine.org/for-patients-and-visitors/patient-information/conditions-treated-a-to-z/difficulty-swallowing-dysphagia (accessed 2023-06-26).

4. Lagos, H. N. C.; Santos, R. S.; Abdulmassih, E. M. da S.; Gallinea, L. F.; Langone, M. Characterization of Swallowing Sounds with the Use of Sonar Doppler in Full-Term and Preterm Newborns. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4399192/ (accessed 2023-06-28).

5. Barium X-Rays (Upper and Lower GI). https://www.hopkinsmedicine.org/health/conditions-and-diseases/barium-xrays-upper-and-lower-gi#:~:text=What%20are%20barium%20X%2Drays,polyps%2C%20hernias%2C%20and%20strictures (accessed 2023-07-26).

6. Dysphagia. https://www.mayoclinic.org/diseases-conditions/dysphagia/diagnosis-treatment/drc-20372033 (accessed 2023-07-26).

7. Esophageal Manometry. https://www.mayoclinic.org/tests-procedures/esophageal-manometry/about/pac-20394000 (accessed 2023-07-26).