Smart Mask

Noelle Papineau, Sara Alkhouri, Kristen Santoro
Department of Electrical, Computer and Biomedical Engineering: University of Rhode Island

Motivation and Description of the Problem/Need: COVID-19 has quickly spread around the globe, resulting in the deaths of over two million people. According to the Center for Disease Control (CDC), "the principal mode by which people are infected with SARS-CoV-2 (the virus that causes COVID-19) is through exposure to respiratory droplets carrying infectious virus" [1]. Transmission of respiratory droplets can result from breathing, coughing, speaking, or sneezing. Healthcare professionals protect themselves and their patients by wearing face masks, which help prevent the spread of respiratory droplets. In a study conducted using data from the U.S. and U.K., frontline healthcare workers have a 12-times higher risk of contracting COVID-19 in comparison to the general public [2]. Therefore, monitoring the health of these frontline workers is vital. Based on a survey conducted by our team in October 2020, only 11.2% of healthcare professionals reported that they undergo mandatory COVID-19 testing. To identify the user's needs, the survey also asked participants about their main concerns regarding their current personal protective equipment. Results are shown in Figure 1.

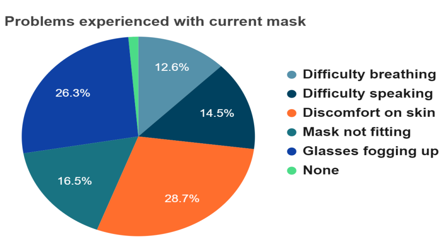

Figure 1: Diagram showing the most common problems healthcare professionals encounter when wearing a mask.

Ninety eight percent of survey participants reported experiencing at least one problem while wearing a mask in the workplace. Out of 189 responses, 84% experienced discomfort on the skin or ears. The survey results influenced the design of a prototype that both solves a problem and meets the needs of the intended user.

Design goals: The goal of this project was to create a custom-fit, sensor enabled mask for healthcare professionals to monitor symptoms related to COVID-19. To ensure that the mask is effective and comfortable, 3D face scanning was used to create a custom fit mask that fits properly on the nose, cheeks, and chin contours of each individual. Using a custom fit mask frame improves the design in two important ways. First, the custom seal that the frame provides limits the amount of respiratory droplets that escape from the top, sides, and bottom of a typical mask. Second, the mask is more comfortable to the user because it fits them properly. The 3D-printed design will be used as a mask fitter which can be placed over a surgical mask or a cloth mask to secure it and seal the edges to the face. Allowing the user to change the mask is important because it will keep the area sterile. To monitor the breathing of users, an Inertial Measurement Unit (IMU) sensor was mounted on the frame of the mask to detect motion. Monitoring the motion of the mask can help distinguish between different respiratory actions such as coughing, breathing, and talking. The main goal was to detect the motion features associated with coughing, a key symptom of COVID-19. To rule out normal respiratory actions, data of talking and breathing was collected. The design's combination of protection and symptom monitoring helps keep users consistently safe and reassured.

Competition and differentiation: Current personal protective equipment has been mass manufactured, leading to an increase in generic fitting masks that may not adequately protect the user. In fact, about half of the healthcare workers surveyed reported that they have used a loose or improperly fitting mask in the workplace. The Smart Mask design improves the overall fit of the mask because of its custom fit. Other researchers and engineers have experimented with embedding sensors in masks. At the University of California, Davis, researchers are developing a simpler, less expensive alternative to cardiopulmonary exercise testing (CPET) for lung cancer patients. Their mask is designed to measure respiration rate, activity, and concentrations of carbon dioxide and oxygen, [3]. In comparison to their design, our proposed design is smaller and more compact, making it less cumbersome to wear for an extended period. In another study conducted in the United States, researchers used two devices for cough detection, a smartphone and smartwatch. Using two devices led to synchronization issues, which negatively affected the accuracy of the coughing data [4]. Their use of audio data for cough detection can be problematic in their design because another individual's sounds can interfere with the data. Our design limits the data to the unique movements of the person wearing the mask. Our solution has also taken price and availability into consideration. In comparison to other specialized sensors, IMU sensors are an inexpensive component used in many electronic devices such as smartphones and smartwatches. Our team has also experimented with a contact microphone to detect vibrations in addition to the motion sensor. Although this added sensor would improve the accuracy of the mask, our team is focused on perfecting the use of the IMU to keep the cost and weight of the product low.

Design process: The initial design proposal consisted of a sensor enabled mask with a fan to assist breathing. However, after extensive research and survey of the main demographic, it was clear that comfort and effectiveness were larger areas of concern than difficulty in breathing. Therefore, the decision was made to tweak the design to tailor to the needs of healthcare professionals. The design process included three main objectives. The first was the designing and printing of a 3D-printed custom face mask that supports mounting sensors. The Bellus3D [5] smartphone application was used to scan faces and create 3D mask fitter models that were later 3D printed. The National Institute of Health and Human Services (NIH) has reviewed this mask design and has recommended its use given it is fabricated as instructed [6]. The mask frame's 3D model was then edited to be capable of mounting sensors used for symptom monitoring. An example of the 3D model and mask frame is shown in Figure 2.

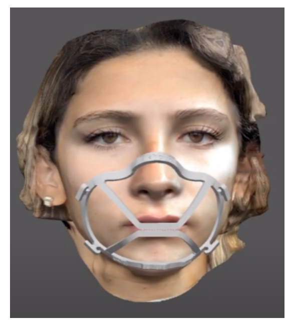

Figure 2: 3D model of face and custom mask frame obtained using the Bellus3D application.

The second goal was to integrate a motion sensor within the mask and interface this sensor with a computer for data logging. Lastly, data was collected and will be used to train a classifier model to distinguish between the different activities.

Prototype of the design: The Smart Mask prototype consists of a 3D-printed mask frame with an attached sensor to detect motion associated with respiratory actions. To collect data for symptom monitoring, an IMU sensor was added to the mask design. This component contains two sensors that detect motion: a 3-axis accelerometer that detects how fast the sensor is moving through space and a gyroscope that measures rotational and angular movements. The IMU sensor communicates through a Teensy 4.0

development board over i2c data protocol. The Teensy 4.0 then writes the data through a micro-USB connected to a logging computer. This design is depicted in Figure 3. The motion data is sampled at 100 samples per second. With more testing and data collection, the goal is to be able to train the software to recognize coughing data versus normal data. The use of a bone contact microphone that would be capable of detecting vibrations associated with coughing has also been researched and considered. Adding this sensor to the design is beneficial because it serves as a second method of data collection in the event that user's movements interfere with the motion data.

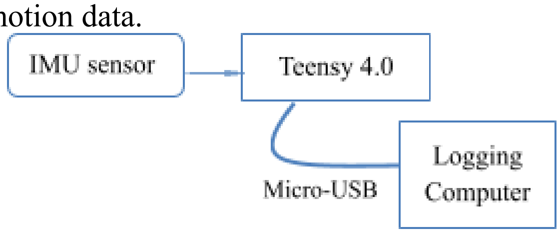

Figure 3: Simple diagram of sensor design

Testing and results: The prototype was tested by attaching the IMU sensor to the mask, shown in Figure 4.

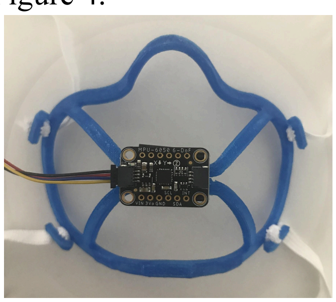

Figure 4: Prototype used for collecting motion data.

The person wearing the mask was instructed to rotate between breathing, coughing, and talking in 30 second intervals. This data was logged in Coolterm. Data was recorded in three separate text files and organized into graphs to distinguish between the three actions more easily. As shown in Figure 5, the motion data associated with coughing was drastically different when compared to breathing and talking. This experiment is currently being repeated to obtain additional results that can be used to improve the accuracy of the classification model.

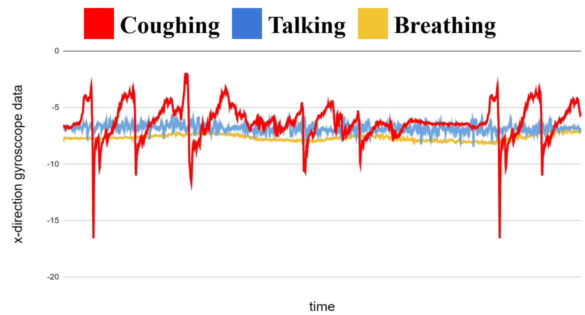

Figure 5: IMU gyroscope data plotted to show difference in motions between respiratory actions.

Value proposition and potential impact: The value of the Smart Mask project is that it has the potential to improve the health and safety of both healthcare workers and patients. Although steps such as social distancing and vaccinations have been taken to slow the spread of COVID-19, the virus has mutated and is projected to continue spreading. Masks will continue to be used in the workplace until the virus is controlled, especially in healthcare facilities. The design and technology of the Smart Mask can be reappropriated for other virus outbreaks or used regularly by frontline workers who are immunocompromised.

References:

1. Alsved M., et al. "Exhaled respiratory particles during singing and talking." *Aerosol Science and Technology*, 2020. (54.11): 1245-1248.
2. Nguyen L., et al. "Risk of COVID-19 among front-line health-care workers and the general community: a prospective cohort study." *The Lancet Public Health* 2020. (5.9): 475-483.
3. Myers B., et al. "Towards Data-Driven Pre-Operative Evaluation of Lung Cancer Patients: The Case of Smart Mask", *IEEE Wireless Health Conference*, October 2016.
4. Ahmed T., et al. "Automated Time Synchronization of Cough Events from Multimodal Sensors in Mobile Devices." *Proceedings of the 2020 International Conference on Multimodal Interaction*, 2020. pp. 614-619.
5. Chen E. Bellus3D. 2018. (1.9.8) [Mobile App] https://apps.apple.com/us/app/bellus3d-faceapp/id1352268131
6. NIH. Mask Fitter by Bellus3D. 2020