Mitt Mates: A Multi-Function Utility Glove

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ABSTRACT

During construction or repair work, users frequently have to carry around several bulky tools. Mitt Mates seeks to resolve that with compact, integrate able sensor modules which users can incorporate into their work gloves, putting needed functionality into the palm of their hand. The Mitt Mates' platform currently supports five packages: LED lights, distance measurement, stud finder, live wire detection, water flow detection.

KEYWORDS

sensors, integrateable , construction, ubiquitous wearables

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1 INTRODUCTION

In the Do-It-Yourself (DIY) and construction industries, users need tools such as multimeters, measuring tapes, stud finders, and other instruments as they work. The amount of tools necessary for completing a task can hinder user workflow: picture users carrying around heavy toolboxes, walking back and forth between the toolbox and the work area to grab the necessary tool. Mitt Mates simplifies hand laborers' workflow by integrating tools into their gloves. Each of the tools is its own stand-alone modules, giving the end user freedom to put any combination of tools they need for the job onto their personal glove.

The sensor modules we created needed to be have several features, the most important of which are robustness, compactness, lightness, and stand-alone functionality. To satisfy these design requirements, we built analog electrical circuits from scratch that mimicked the functionality of large bulky tools while miniaturizing them, ensuring they would fit onto a small portion of the glove. Where we couldn't create our own analog circuit, we chose light, small, Arduino-compatible hardware. The final design constraint was that the presence of the modules should not impede user motions associated with work e.g. holding items, picking up things, gripping. This limited aspects of the design, from how large the sensors could be, to how they were shaped, and where on the glove the sensors could be attached.

2 BACKGROUND AND RELATED WORK

It is estimated that homeowners in the US spend upwards of $300 billion annually on home repairs and maintenance [10]. The wearables industry has barely explored products in construction. In our market research, we found no other products with the same objective as Mitt Mates, improving workflow through sensor integration. Most construction-focused, smart wearable products involve ways to better determine the working conditions and have methods for hazard avoidance for construction workers [3, 4, 11, 16, 17].

One of the main sensors that we implemented in Mitt Mates is a non-contact AC voltage detector. In the DIY/construction industry, voltage detectors are commonly used for determining which circuits are still live. Other wearables that inspired our project include Crockett and Gulley's work on using capacitive coupling to construct a detector [4]. They initially received many false positives, but found that using a microcontroller to process data can eliminate many problems.

Another sensor that we implemented in Mitt Mates is a water flow detector. For people who choose not to call plumbers (and plumbers themselves), it is useful to determine if fluid can pass through pipes. By knowing locations of the pipe where water can pass through, it is possible to determine where clogs may be present. Guyot describes a wearable device that can accurately recognize water flow events in the medical context [7]. Their methodology utilizes a spectral cover which is able to recognize water flow in a noisy environment. We explored water flow event recognition in a different way, using the analysis of capacitive differences through a pipe.

Most wearable smart gloves that have been prototyped and researched are gloves that are in the medical industry. From gloves that focus on individual health and therapy [2, 13, 14] to disabilities [8, 12], we found that most of these wearables had many important similarities to ours regarding their human-computer interface: they aimed to be comfortable, user-friendly, intuitive, and non-intrusive.

Other factors we needed to consider involved the user's ability and choice to be able to use their own glove that they already owned at home. The downside to creating a glove that was built with all of the sensors and functionalities mounted to it is that users would be forced to buy a product that may not conform to their hands well or may not have certain, non-electronic functionalities like padding. Along with previous research [6], we conducted surveyed potential users about what they looked for in an all-in-one glove

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that could help them with their home maintenance activities. We received feedback indicating that they preferred to use their own gloves, wanted the ability to wash it, and have the option to use only certain sensors at certain times. One person that we surveyed described how they would like to sometimes use these gloves for gardening, while also sometimes using it for working with electronics or carpentry. After considering this feedback, along with constraints and polling data from Dipietro [6], we concluded that we wanted to strive for a design where sensors were detachable and users were able to choose the purpose of the glove.

3 OUR SOLUTION: MITT MATES

To reach our goal of meeting user-desired qualities, as well as the functionalities important in our target industry, we created Mitt Mates, a multi-function utility glove with five different sensors:

(1) LED Lights
(2) Distance Measurement
(3) Stud Finder
(4) Live Wire Sensor
(5) Water Flow Sensor

Figure 1: Mitt Mates Prototype with all sensors attached

All sensors integrated into the glove is shown in Figure 1, and individual sensors (excluding the stud finder) is shown in Figure 2. These sensors were developed in weekly sprints under the Scrum/Agile standards, and IEEE engineering standards in education were followed during development.

4 GLOVE FEATURE/SENSOR OVERVIEW

In this section, we will discuss the technical details of how we built each sensor, experimental feedback, and design choices. The sensors were controlled to turn on/off using a switch, and an OLED module attached to the back of the glove displayed information regarding each sensor.

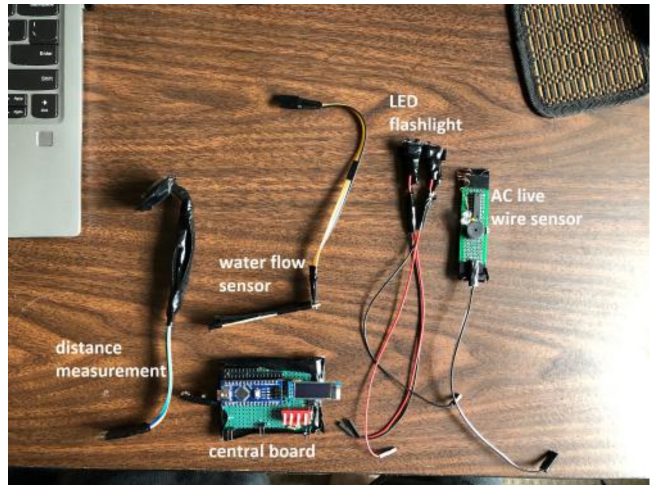


Figure 2: Mitt Mates Sensors excluding the Stud Finder

4.1 Central Processing Board

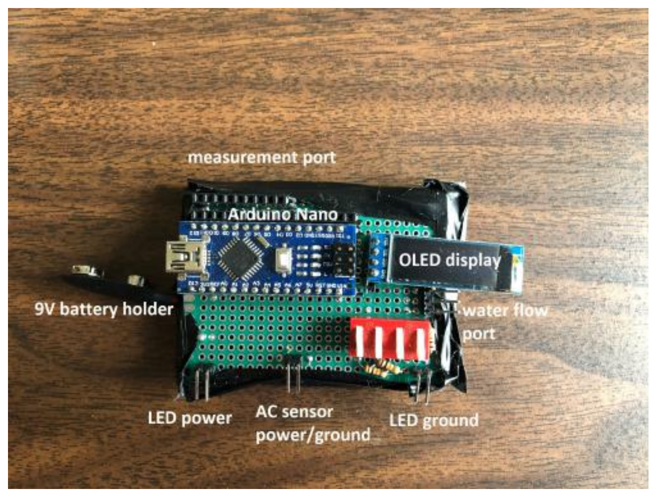


Figure 3: Central Processing Board for Mitt Mates

To control the five different sensors, we used an Arduino Nano as our main microcontroller to handle data processing and feedback to the user. This was powered with a standard 9V battery. The goal of Mitt Mates is to make sensors detachable so users have the option to use certain sensors when they need it. For example, if a user just needed to use the AC live wire sensor and the LEDs, the user can simply attach those two sensors, plug them in to the proper port, and flick on the proper switch, as shown in Figure 3.

The OLED display would indicate the distance measured in inches for the distance measurement sensor, and the capacitance values/whether or not water flow is detected for the water flow sensor. Because the live wire sensor, stud finder, and LEDs are all analog circuits and don't need any digital processing, they have their own individual indication mechanism that they are on. For the live wire sensor, a piezospeaker and LED will beep and flick, respectively, if a live wire is detected. For the stud finder, a piezospeaker will beep if a stud is detected.

4.2 LED Lights

We incorporated LED lights that the users could use in lieu of flashlights. These LED lights come in different colours (white, blue green) and are attached to the fingers of the glove. The white LEDs are shown in Figure 1. The blue and green LEDs are shown in Figure 9(a).

4.3 Distance Measurement

Incorporating distance measurement into the system of sensor was one of our top priorities. Distance measurement is one of the most frequent problems during construction and requires bulky external tools ranging from large measuring tapes to measuring wheels. We wanted to create a compact, accurate sensor that was applicable for all surfaces.

4.3.1 Initial Attempt: Accelerometer. Our first attempt at distance measuring involved using an accelerometer, specifically the Adafruit MMA8451 Triple-Axis Accelerometer. This choice was inspired by iPhone which uses an IMU within the phone to determine how far the user has moved. This choice was also motivated by the compact size of the accelerometer, and that the accelerometer did not need to be pressed against a surface for use. We found a manual from the designer of the accelerometer[15], Freescale, which detailed how to use the accelerometer for a distance measuring application. However, the manual is from 2007 and the provided code references functions that are not present in the Arduino library. This, combined with the inaccuracy of the measurements resulting from compounding errors from the double integration from acceleration to displacement, led us to abandon the accelerometer as the sensor used for distance measurement.

4.3.2 Initial Attempt: Trackball. We pivoted to using a trackball after encountering difficulty with the accelerometer. We tried to use Seeed's Grove Mini Trackball for initial prototypes. Unfortunately, after experimental testing, we realized using the trackball came with difficulties. First, the documentation for the sensor was very limited which made it hard to calibrate the trackball as it was difficult to interpret the measurements we were getting. Secondly, using the trackball on bumpy or uneven surfaces changed the measurement significantly, and using too much pressure on the sensor also cause the ball to slide instead of rolling. Testing done with the trackball revealed up to 10x differences in values measured over the same distance and on the same surface, with the only change being the amount of pressure applied by the user. The trackball's rolling mechanism is too unreliable, so this sensor was abandoned as well in our search for a distance measurement sensor.

4.3.3 Final Attempt: Optical Mouse Sensor. We finally settled on using an optical mouse sensor, specifically the ADNS9800, to measure distances across a surface. One of the key reasons we chose the optical mouse sensor over the trackball is because of the amount of documentation that it had. Although the trackball gave us count values of how much the sensor changed in the x and y direction, we didn't have information like counts per inch (CPI) or dots per inch (DPI) that could allow us to properly calculate how far the sensor had traveled. The optical mouse sensor, on the other hand, had that information. The ADNS9800 had a 8200 CPI, with increments of 200, making its resolution for distance measuring about 1/40 of an inch. Through this, we were able to calculate how many inches we were moving in the x and y direction by taking each count value and dividing by 8200. For example, if it counted 8200, then we know we moved an inch.

Another benefit to the optical mouse sensor as opposed to the trackball and accelerometer is that it performed well with uneven or bumpy surfaces. With the trackball, measuring surfaces that have small divots would count the distance inside the divot. With an optical sensor, we are able to measure just the distance from point A to point B, which is the typical application for home repair/maintenance activities like hanging a frame.

One disadvantage of using an optical mouse sensor, trackball, or accelerometer as opposed to a regular standard tape measure is that distance measurement can have a large margin of error due to the possibility of the finger the sensor is attached to moving up or down. To address this problem, we calculate distance based off the changes in x and y using Pythagorean Theorem. With the change in x and y, we calculate the hypotenuse to calculate the actual distance traveled from the starting position.

4.4 Stud Finder

Knowing what is behind walls is an important part of construction and DIY work. Often, users need to know where studs are located in walls, because these are important to the structural integrity of the building. For this reason, the stud finder is an essential part of a toolbox. Stud finders detect density differences in the wall, indicating wood studs, by using capacitance plates to detect differences in the dielectric constant of the wall, which is directly related to its density.

Knowing the importance of this sensor, we decided to try and build a sensor module so that users can integrate it into their gloves. There are many different kinds of stud finder designs out there, but we found a simple circuit by YouTube user 'vk2zay' on YouTube using components available in our lab with videos explaining the circuit, which appealed to us. We built the circuit shown in Figure 4.

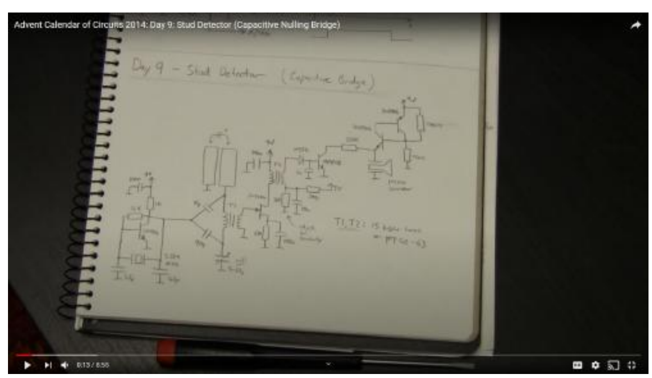
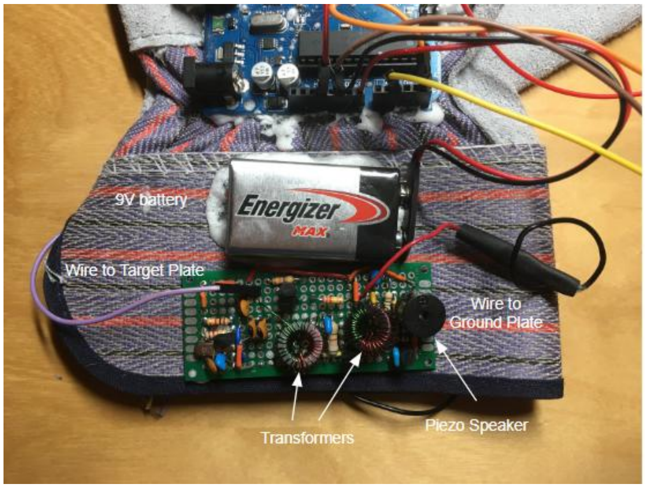
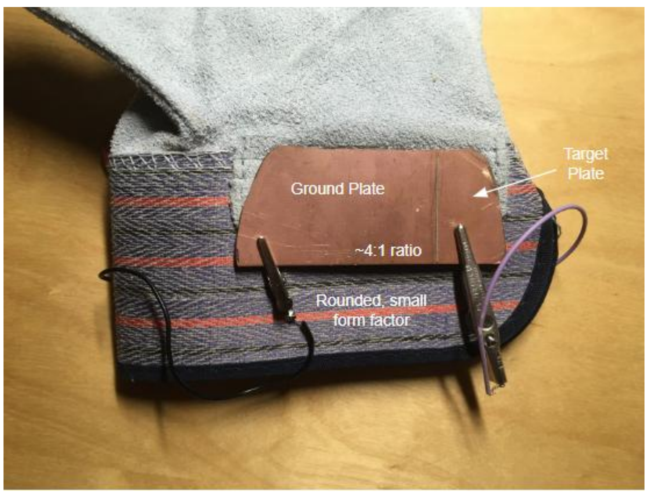


Figure 4: Screenshot of stud detector circuit



(a) Stud Finder Module integrated into glove, top view



(b) Stud Finder Module integrated into glove, bottom view

Figure 5: Stud Finder Module

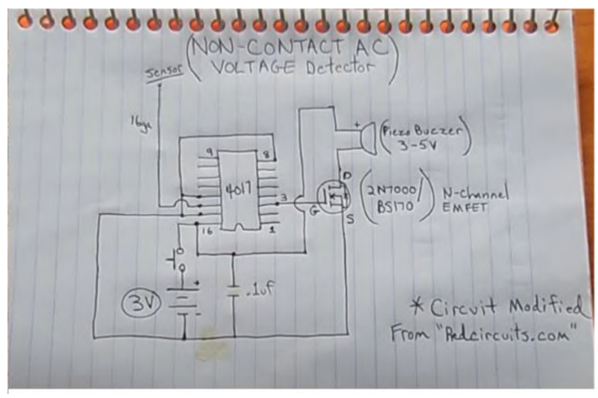
We were never able to make this circuit function properly. We troubleshooted extensively, from transplanting the circuit to different breadboards, consulting Kip Coonley and Chris Bingham, trying different components, probing the circuit with a multimeter, to simulating the circuit in PSpice, which mirrored our malfunctioning circuit. Through our troubleshooting, we determined that either our interpretation of the circuit shown in the video was incorrect, or the circuit diagram shown in Figure 4is incorrect.

Although the circuitry was not functional, we wanted to visualize what a stud finder module would look like if integrated into a glove. We soldered the components to a protoboard and cut a copper target capacitive plate to an ergonomic form factor attached the wrist.

4.5 Live Wire Sensor

Live wires are everywhere in our daily lives, from walls, receptacles, to the power lines outside our homes. Any current flowing in a live wire creates an electromagnetic field (EMF), and the current returning via the neutral wire does the same, with a different polarity. A non-contact AC voltage detector detects these changing magnetic fields around AC energized objects [5]. Live wire sensors are useful for situations where users may need to check to see if a receptacle is live before performing work on or near it. This is an important safety mechanism to prevent electrocution. Live wire sensors can also be useful if users need to track where wires run behind walls to avoid damaging them.

(a) Live Wire Mitt Mates Sensor



(b) Live Wire Sensor Circuit

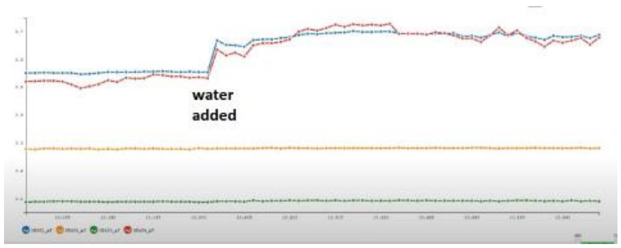
Figure 6: Live Wire Sensor and Circuit Diagram

Our AC live wire sensor utilizes a 4017 decade counter, an N-channel effect transistor (2N7000), and LEDs and a piezospeaker to indicate when a live wire is detected. An antenna picks up pulsating EMFs and brings the clock pin of the decade counter high, which in turn changes the value of the outputs. The output going high or low triggers whether the LED/piezospeaker indicates that there is a live wire. This sensor, along with its circuit diagram are shown in Figure 6.

4.6 Water Flow Sensor

For the water flow event sensor, we used a Texas Instruments FDC1004 Evaluation Module to track capacitive changes throughout a pipe. The evaluation module uses a simple I2C interface that can be configured to the Arduino. We used a library written by

Stefan Kruger that configures the evaluation module to the Arduino interface [9]. The evaluation module has two capacitive plate sensors in which the FDC1004 chip processes to convert into a digital value.



(a) Water added to PVC pipe

(b) Water drained from PVC pipe

Figure 7: Water Flow Sensor Capacitive Graphs

To determine whether water is flowing or not, we conducted a series of tests to determine ambient capacitance in the air, and the capacitance detected when water is flowing through a PVC pipe. To do this, we mounted the capacitive plate under a PVC pipe and ran water through the pipe. We kept a running average of how the capacitance changes to determine the average capacitance detected when water is flowing, and when it is not. The spikes and falls of the capacitances is shown in Figure 7.

With this average, we set a threshold for what is considered having water flow and not having water flow. This then outputs a binary value onto the OLED display that tells the user whether or not it detects water flow. If the detector is ran through a pipe in which it detects water and then suddenly does not, even while water is still supposed to be flowing, then this can indicate to users whether there is a clog present at that location.

4.7 Risks and Tradeoffs

4.7.1 Risks. We followed a reasonable plan in our product design. First identify important tools that can be integrated into a glove, create a solution, make it into a module that can be integrated into a glove. The biggest risks to our project come from investing time and effort into sensor solutions that will not work out, such as the stud finder. The degree of difficulty in sensor implementation perhaps should have been weighted higher in our decision matrix so that we put our time and effort into modules that have a higher chance of working, such as the live wire sensing or the distance measurement. However, the importance of the sensor to the end user can justify working on it, even if the chances of success are low. Stud finders are an important tool, and perhaps the bulkiest

	Affordability	Simplicity of Implementation	Familiarity with Technology	Usefulness	Compactness	Score
Weight	0.2	0.3	0.1	0.3	0.1	
EMAT	1	1	1	4	2	1.8
Capacitance Plate	5	5	1	4	5	3.8
Ultrasound	1	1	3	3	1	1.7
RF receiver and transmitter	1	3	1	2	2	1.8
Accelerometer	3	1	2	5	5	2.6
Stud finder	5	3	1	3	3	2.9
Trackball sensor	3	3	2	5	5	3.2

Figure 8: Decision Matrix to Evaluate Sensor Viability

of the ones we chose to eliminate from the toolbox, so we do not believe it was a mistake to attempt to try and create our own. In the future, designs will be more carefully vetted. An example is that before copying the circuit onto the breadboard and troubleshooting it, we should have first ran a simulation in PSpice to confirm that it worked.

4.7.2 Tradeoffs. The limited space on the glove made for some interesting tradeoffs in our final design. One tradeoff is in the stud finder's capacitive plate design.

The stud finder's sensitivity is directly related to the size of the copper capacitance plate. The need to maximize the size of the copper plate competed with the need to make the design comfortable to use for the user. For the ease of use, the plate's location was determined to be best if it was on the front of the hand, because holding your hand flat to the wall is more natural facing forward. With this in mind, if the capacitive plate was very big and unwieldy, the user would not be able to perform necessary motions with their hands, such as closing their fists or gripping tools. Our team decided to value user ergonomics over the sensitivity of the device, and for this reason we chose a small, form-fitting shape for the capacitance plate, which would rest on the user's wrist.

Since we had a limited window of time to complete this project, we opted to prioritize functionality over appearance of the glove. Hence, we had working sensors however the prototype was not very appealing to the eyes. We also had to pick the sensors that we thought we would finish the fastest and abandon some avenues we were exploring, for example, the depth finding. We also had a limited budget for the project therefore we prioritized cheaper sensors to allow us room to buy multiple quantities for easier testing. This was a tradeoff we had to make between one really great expensive sensor, vs. several inexpensive sensors that perhaps were not as sensitive/accurate.

5 OTHER SOLUTIONS

The initial idea we were considering was creating an all-in-one glove that the user would purchase. As stated before, we pivoted away from this idea after surveying users and realizing that 1) Users want to use their own glove, and 2) Having the sensors there when not in use is inefficient.

Another idea that we explored was creating a multitool but several of the functionalities we wanted to implement involved using sensors, so it made more sense to create them separately.

We considered implementing other functionalities and creating different sensor modules. Based on our decision matrix in Figure 8, we analyzed factors like cost and difficulty of implementation to narrow down which modules to implement. For example, we were thinking of creating a depth-sensing sensor using EMAT, but realized that EMAT technologies are highly-custom and very expensive to implement therefore we chose not to pursue that route.

6 DESIGN CHOICES AND CONSIDERATIONS

Our main priority when designing the glove was the user's comfort and ease of use. We decided to use Velcro to attach the sensor modules to the glove. The sensor modules would be strongly adhered to the glove while in use, and when not, the velcro would also allow the user to easily take off the sensors. Using velcro patches also allows the user to customize the placement of their sensor modules. For example, the velcro patches go around the wrist, allowing the user to place the OLED screen wherever is convenient on the wrist.

Although we didn't end up using the trackball, we had created an adjustable strap for the trackball. When the user wanted to measure distance, he could turn the trackball sensor out as normal to use it, and when he was done, he could turn it back over the nail bed so the sensor would not get in the way of his index finger, as illustrated in Figures 9(a) and 9(b).

With our current design, Mitt Mates reduces the barrier to construction and DIY projects by providing a cheaper and more accessible alternative to necessary tools. This creates a positive economic and cultural impact as it allows more laymen to try DIY projects and fosters community around home improvement. We also designed Mitt Mates to have a positive environmental impact as the use of plastic is reduced (no large plastic encasing needed unlike measuring tape and current studfinders). The sensors we created are also low-power and low-voltage, increasing battery life and reducing the use of energy. Since Mitt Mates reduces the risk of hurting oneself when carrying/using too many bulky tools at once, it also has a positive security and safety impact.

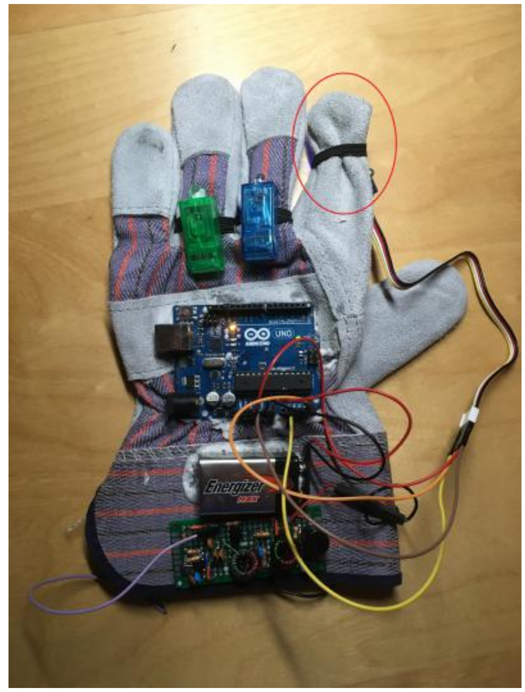
Regarding public health, welfare, global, social, and ethical factors, Mitt Mates has little to no impact on them.

7 RESEARCH AND SELF-LEARNING ACTIVITIES

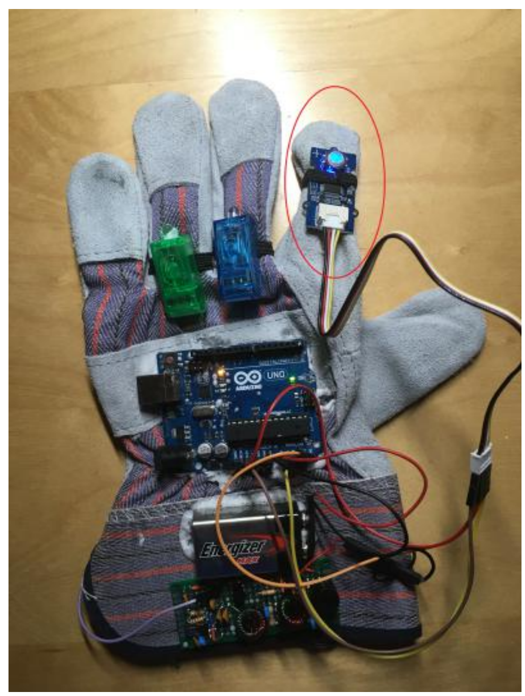
Most of the sensors we used were new to us. We had to research the possible avenues we could take to solve each problem (measuring distance, detecting live wires) and then conduct more research on finding the best circuit to implement each sensor.

After the coronavirus outbreak, we learned how best to work together remotely, split work evenly, and help each other debug circuits. It was difficult to transition to remote collaboration so suddenly, but we adjusted to it by doing trial Zoom meetings and communicating more frequently.

Our group gained a lot of 'soft' skills over the course of the project. During our frequent prototype building meetings our team really came together over our love of chocolate milk. While working together, we learned to trust each other with the different parts of the project, and our interpersonal team-based communication became friendly and encouraging, while still remaining professional. We hope to use our experience as a template for continuing to grow in the teams we will be in throughout our future professional careers.



(a) In use: Sensor turned towards index finger pad



(b) Not in use: sensor turned outwards

Figure 9: Trackball Sensor Design

8 FUTURE WORK

As of right now, we have a very raw prototype that mostly works, but there is so much more that can be done to make this a commercially-viable product that can transform the DIY/construction industry.

8.1 Form Factor

Currently, on our protoype we have exposed wires and circuit boards. The first step would be to miniaturize these circuits by developing IC chips and then creating a PCB for mass-manufacturing. We would also develop small, lightweight chassis to enclose the circuit and wires. Futher, currently we attach sensors using velcro. The velcro patches are sewed onto the glove. We would have to think of another way to attach velcro patches onto the user's glove without permanently changing it.

8.2 Stud Finder

A different circuit model would be chosen to base the stud finder circuit on. There are patents for old stud finder models that have expired[1]. Moving forward, I would base a stud finder module on one of these patents because we know that they work. The patent designs were not initially chosen because they are complex, but if we had more time to work on this project it would be a feasible route.

8.3 Live Wire Sensor

Aside from miniaturizing the sensor, one of the main problems with the live wire sensor is that there is no way for the user to be able to adjust the sensitivity of the sensor. Being about 10-20 feet away from a high voltage line that runs in the streets can trigger the current sensor, which makes it a problem for workers that may be working with smaller live wires outside. The ability to tune the sensitivity of the sensor can counteract certain glitches involved with using the 4017 decade counter. The clock pin in which the antenna is connected to is very sensitive. For that reason, the LED/piezospeaker output can get stuck at high sometimes, thus requiring the user to reset the system.

8.4 Water Flow Sensor

Like the other sensors, the water flow sensor needs to be miniaturized to reduce clutter and bulkiness of Mitt Mates. However, one key addition and future point of work can be to implement a machine learning algorithm for detecting fluid flow. As of right now, the sensor gives a binary determination of fluid flow through pipes based off an experimental threshold for capacitance values for the presence/absence of fluid. A machine learning algorithm that can keep the running average and change of certain types of fluid capacitances can further enhance the accuracy and versatility of the sensor. One avenue that we can take this project in is exploring the method of spectral cover discussed in [7]. This not only gives us another algorithm for determining flow, but it can reduce noise.

9 CONCLUSION

We identified an opportunity to break into the construction and carpentry technology market, which uses technology that is decades behind. Most of the sensors and tools workers use can be miniaturized and integrated into users' workflows. After identifying which tools we can replace with our product, we created five sensor modules for Mitt Mates: LED lights, distance measurement, stud finder, live wire detection, water flow detection with future plans for depth finding, RF capability, and more. Our immediate next steps would be to debug and optimize all circuits to minimize voltage and power usage, then to miniaturize the circuits and build the chassis casing for each module. Through Mitt Mates, we want to continue helping all who create with their hands by putting users' tools into the palms of their hands.

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