4-28-2024

UAH Moonbuggy Task Tool Force Measurement Module

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UAH Moonbuggy Task Tool Force Measurement Module

by

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An Honors Capstone

submitted in partial fulfillment of the requirements

for the Honors Diploma

to

The Honors College

of

The University of Alabama in Huntsville

Date

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Table of Contents

Abstract

The UAH Moonbuggy team is a senior design class that competes annually in the NASA Human Exploration Rover Challenge. In this challenge, teams design and build a human-powered vehicle that transports two riders over a series of obstacles. Additionally, the riders are required to use a team-designed, handheld device to accomplish a series of additional tasks. The task tool for this year's competition required a gripper mechanism that must be capable of applying at least 15 pounds of force. This capstone project is to design a device that will verify the completion of this requirement by measuring the force output of the task tool.

The device consists of a force sensitive resistor, Arduino Uno, and a liquid crystal display. The components selected were chosen for their low cost, ease of use, and durability, particularly the force sensitive resistor. Each component has its own 3D printed mount that provided simple solutions to mounting the device on the tool, creating a product that can be attached with relatively low impact of functionality of the tool. Ultimately, the device was able to successfully measure and display force output from the gripper, succeeding in the goal of demonstrating the capability of the team-developed device.

Introduction

The NASA Human Exploration Rover Challenge (HERC) is a yearly competition for high school and college students that is hosted at the Space and Rocket Center in Huntsville, Alabama. In this competition, teams are tasked with designing and building a human powered vehicle, called a rover or moonbuggy, that two drivers use to navigate a course of extreme terrain. In addition to this vehicle, teams are tasked with constructing a handheld device, called a task tool, to accomplish a variety of tasks while on the course. The team has eight minutes to traverse the ¾ mile course and complete as many obstacles and tasks as possible for points, so an efficient task tool is nearly as important as an effective rover. The score on the course is added to teams' report scores, and the highest scoring team is the victor.

Every year, the missions the task tool must accomplish change. This year, there are four tasks the task tool must be capable of completing, with a fifth task that does not require the use of the task tool. The first task requires teams to use a task tool mounted light source to trigger a photosensor. The second task consists of using the task tool to clear a solar panel of dust, allowing it to power an indicator light. The third task has a rover pilot dismount the rover, put on EVA gloves, and use a provided hand tool to remove a fixture plate. This task does not require the team-designed task tool. Task four has the team use the task tool to attach a provided clamp-ended cable to two posts. This task is comparable to using jumper cables. Finally, the fifth task has teams remove two sealed containers from a table using the task tool.

Overall, the task tool missions make up 20% of a team's score, the same weight as the course performance. With this is mind, it is critical for a team to complete as many tasks as possible as effectively as possible to remain competitive in the competition. This means that verification of task tool performance is an important step of the design process. This capstone project is intended to provide performance verification for task four of the HERC competition by constructing a removable force measurement module that will provide live feedback on how much force is being transmitted through the tool.

Task four has been identified by the UAH team as the most difficult task, with transmitting enough force to operate spring loaded clips being the critical hurdle. This project will design a module that uses a force sensitive resistor to measure the applied force at the end of the task tool. In the HERC guidebook, the clamps have been specified to require no more than 15 pounds to open. This project will provide a way to verify that the task tool can apply at least that much force, thus satisfying the mission requirements. As this has been identified as the most likely failure point on mission day, verification of the tool's performance is an important part of the testing process leading up to competition. This project will provide an easy and reliable way to confirm the performance of the task tool, aiding the team as they prepare for competition.

Background

This project relies on two primary components, a force sensitive resistor and a liquid crystal display. Force sensitive resistors (FSRs) are a cheap, lightweight way to measure and/or detect force. These elements act as variable resistors in an electrical circuit, decreasing resistance as force is applied to them. With no force applied, FSRs typically have a resistance in the order of megaohms, which decreases logarithmically as force is applied. FSRs typically consist of two membranes separated by a thin air gap [1]. One of the membranes is a polymer sheet that has a sensing film applied to it. This sensing film consists of both conducting and non-conducting particles suspended in a matrix. The other membrane has conducting electrodes, so as force is applied to the sensor, the particles touch the electrodes, changing the resistance of the film [2]. The two layers are then laminated together using an adhesive layer [1]. This creates a durable, flexible, and simple interface that can handle somewhat hostile environments, making them ideal in applications where rough use is intended [2].

Liquid Crystal Displays (LCDs) are electronic devices that apply a varying voltage to a layer of liquid crystals. The application of this varying voltage changes the orientation of molecules in the liquid crystal layer, which in turn changes the way that light passes through the layer. Liquid crystals are a structure that is in between being a solid and liquid, as the molecules can flow past each other and rearrange into ordered patterns. These patterns can be characterized based on the chemical structure of the molecules. There are two different kinds of liquid crystals that can be used in LCDs, nematic and smectic. Nematic crystals align themselves with their axes in parallel, while smectic crystals align themselves in sheets. There are minor differences in how the different types of crystal impact the optical performance of the display, but this goes beyond the scope of this project. Considering the use of LCDs, while a small amount of power goes into directing the orientation of the liquid crystals, the vast majority is spent powering the back light of the display. This back light goes through the crystals and is adjusted to display the desired color. Overall, LCDs are used in a wide range of electronic display devices and are known for their low power consumption [3].

Material Selection and Constraints

The design statement for this project is to create a low profile, easily removable device that can measure the force output of the task tool gripper. This statement constitutes many derived requirements that must be met for the project to be viewed as a success, in addition to the explicit requirements of measuring force output from the tool. The full list of requirements for this project is outlined below in Table 1.

Table 1. System Requirements

Requirement	Description
1	Must be able to accurately measure force output from the UAH Task Tool gripper mechanism.
2	Must be able to measure up to 20 pounds of force.
3	Must be able to attach to the task tool without need for modification of the tool.
4	Must not impede use of the task tool gripper.
5	Must weigh under 3 pounds.
6	Must display measurements in an easy-to-read way.
7	Must be a fully contained module with no external connections.

These constraints were chosen to ensure the practicality of the device being created. Requirement one is the goal of the project, without which there would be no point for the device. Requirement two sets a reasonable bound for measurements, as the task tool needs to be able to output at least 15 pounds. Requirement three is necessary to prevent disruption to the development of the task tool. This module should not impact the functionality of the task tool in any way, so it should be able to work without the need to change any part of the final design. Similarly, requirements four and five are necessary for testing of the device. The task tool must be in a usable condition to provide realistic force output, and the measurement device must not add an amount of weight that would make the task tool overly difficult to use. Requirement six is a quality-of-life objective, as displaying the measurement live to the user is something that would make the device more practical when using it to test in a variety of situations. Finally, requirement seven was necessary so that the module didn't need to be tethered to a computer or another power source or display. This allows for increased flexibility while the device is set up on the task tool. With these requirements in mind, the selected components for this project are listed below.

- Arduino Uno R3
- LCD 1602 RGB Module
- Force Sensitive Resistor, Thin Film Pressure Sensor 0-30 kg
- Portable power bank
- PLA 3D Printer Filament
- Assorted bolts sized M2-M4

The primary decision factor for these components was cost and accessibility. The Arduino Uno is cheaper and easier to use in this case than a Raspberry Pi, which was the other device considered for controlling the device. The force sensitive resistor (FSR), 3D filament, and bolts were all very cheap and easily accessible, while the Liquid Crystal Display (LCD) provided a high-quality display that was small and easily used. The power bank, which is often used to portably charge cell phones, provided a lightweight, low-profile method of powering the Arduino, removing the need to have it tethered to a computer for use.

Design and Development

The design of the force measurement device began with the electrical implementation of the components that would be used. The implementation of the force sensitive resistor with the Arduino was straightforward, as it is a hookup to the analog input on the Arduino with a 10 Kohm resistor. The LCD is even simpler, with no additional components needed. The schematics used to connect the FSR and LCD are shown in Figure 1.

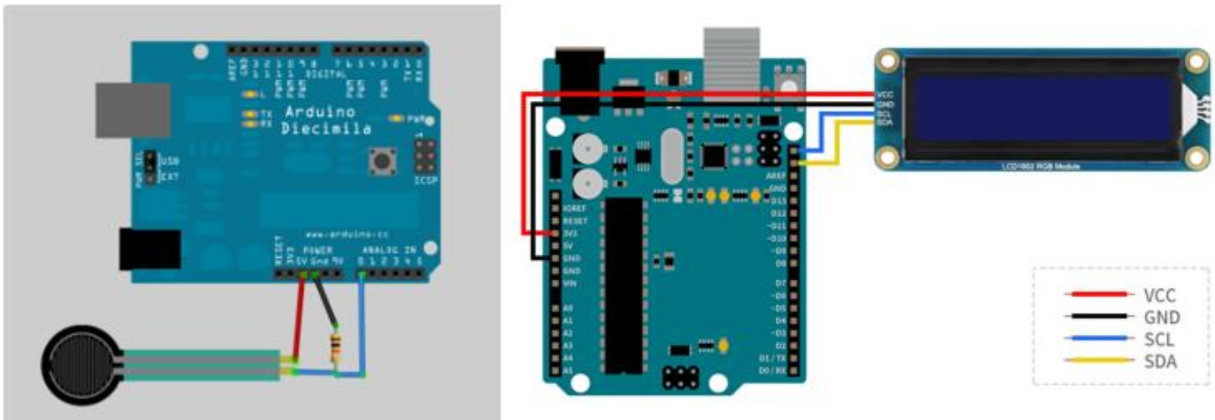

Figure 1. Schematic for Force Sensitive Resistor (left) and LCD (right)

Following the electrical implementation of the components, the software for the device had to be written. The code that was produced for this project utilized the Waveshare LCD library and is heavily based on example code available for force sensitive resistors found on the Adafruit website. The project code, shown in Figure 2, was modified from these examples to display output to the LCD and corrected to match force readings to this specific FSR.

The design of the code is relatively simple, taking analog input from the FSR and displaying a message based on the force applied. The serial monitor was used for initial load testing of the FSR, as the analog input was printed to the serial monitor while the force applied was recorded externally using a scale. From a collection of these data points, an equation for approximate force from analog input was found and used in the program.

Inside the run loop, there are three possible conditions for the device. The first is if the input is zero, which means that there is no force applied. This is represented by a message saying “No pressure” that is displayed on the LCD. If a light pressure is applied, designated as an analog input of below 100, the pressure is declared as too low, and a corresponding message is displayed to the screen. This limit was set based on the necessary operating ranges of the task tool, as the device doesn’t need to be accurate below one pound of force applied. Finally, if a strong enough load is applied, the input is converted to pounds using the experimental correlation determined in testing and output to the screen. This process is run with a one second delay, with the first action done being to clear the display line. This is done to ensure that the screen properly updates with the most current reading.

ForceReading.ino

```
// Written By: Alex DiBenio
// Reads input from force sensitive resistor and displays force in pounds
// to an Liquid Crystal Display screen.
// Code based on example code found at
// https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr

#include "Waveshare_LCD1602_RGB.h" // library for LCD screen use
Waveshare_LCD1602_RGB lcd(16,2);

int fsrPin = 0;      // the FSR and 10K pulldown are connected to a0
int fsrReading;      // the analog reading from the FSR resistor divider
long fsrForce;        // Finally, the resistance converted to force
char force[24];

void setup(void) {
  Serial.begin(9600);   // Debugging info sent to the serial monitor
  lcd.init(); // initialize LCD
  lcd.setCursor(0, 0);
  lcd.send_string("Force Reading:");
  lcd.setCursor(0,1); // Move to second row of LCD
}

void loop(void) { // While running
  lcd.setCursor(0,1);
  lcd.send_string("                "); // clear display
  fsrReading = analogRead(fsrPin);   // read sensor input
  Serial.print("Analog reading = "); // print to serial monitor for testing purposes
  Serial.println(fsrReading);

  if (fsrReading == 0) { // if no force, output "no pressure" message to display
    Serial.println("No pressure");
    lcd.setCursor(0,1);
    lcd.send_string("No pressure");
  } else {
    lcd.setCursor(0,1);
    lcd.send_string("                "); // clear display

    if (fsrReading <= 100) { // Readings below 100 aren't measured
      lcd.setCursor(0,1);
      lcd.send_string("Pressure too low");
    } else {
      // Equation to convert analog reading to force based on testing
      fsrForce = 0.1713*exp(0.0189*fsrReading);
      Serial.print("Force in pounds: ");
      Serial.println(fsrForce);
      lcd.setCursor(0,1);
      ltoa(fsrForce, force, 10);
      lcd.send_string(force); // display reading
    }
  }
  Serial.println("--------------------");
  delay(1000); // Wait one second, then loop
}
```

Figure 2. Force Measurement Code

Once the device was functioning, the mechanical implementation of the device began. The first thing that was considered when designing this device is how it will fit on the task tool. The force measurement module would need to consist of three structures; a “core” that held the Arduino and power supply, the LCD screen to display the measurement, and the sensor itself. These three modules would all need space on the task tool and a method of staying in place. Additionally, the three structures would have wires that ran between them, making avoiding entanglement another point of consideration when placing them on the task tool.

The UAH task tool, shown in Figure 3, consists of two roughly three-foot lengths of one inch square aluminum tubing. These tubes are connected by a 3D-printed hinge (shown in the top right corner of Figure 3). The shorter tube has 3D-printed mounts for a flashlight and broom (not shown). For the case of this project, this half of the tool is unimportant. The longer tube consists of a bike brake handle in the back, a grip in the middle, and the gripper device at the end. Not shown is the brake cable that runs from the handle to the gripper.

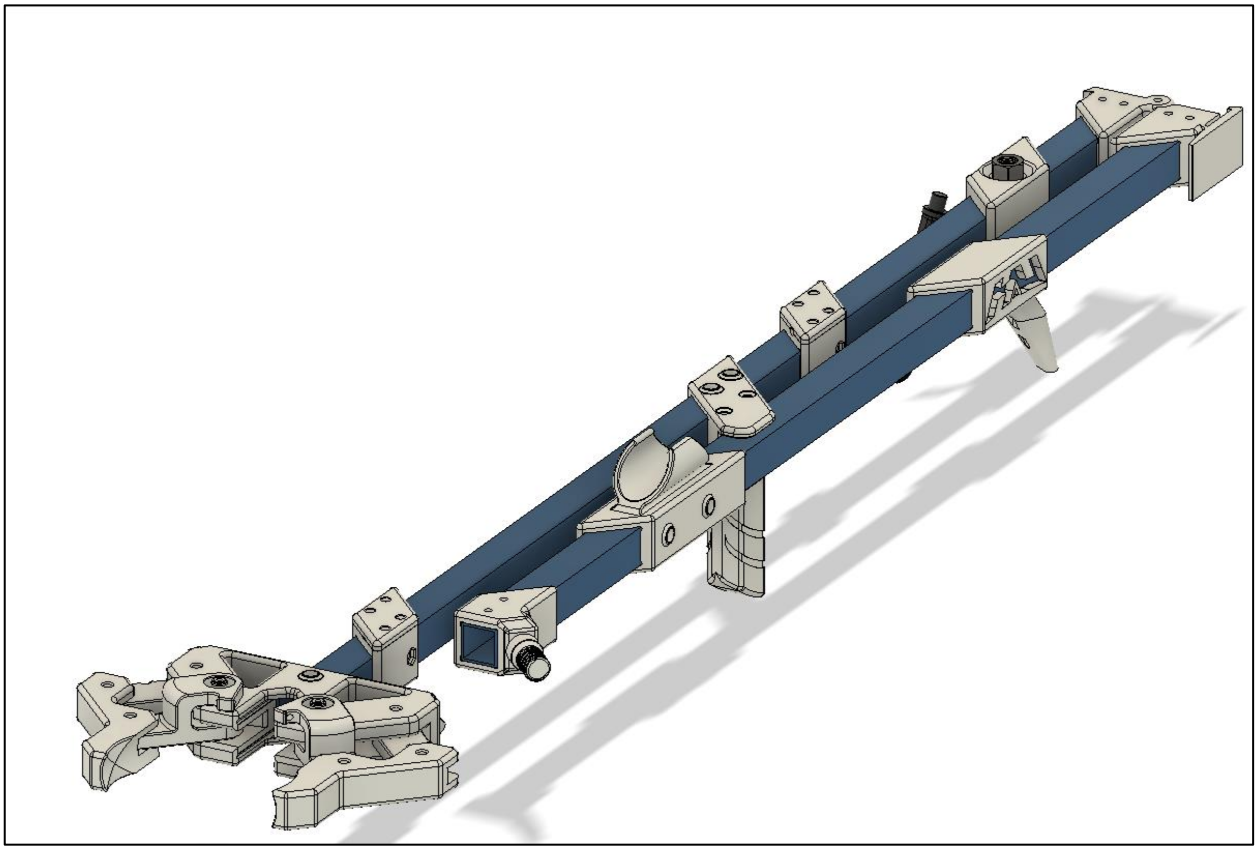

Figure 3. UAH Task Tool CAD Assembly

Looking at the task tool, there is plenty of open space along the tube to mount the power supply, Arduino, and LCD. To save space and increase ease of attachment, the power supply and Arduino mount were combined into a single assembly. This was the largest and heaviest component of the device, and as such required the strongest mounting system. The mount designed consisted of enclosing the power supply in a container, with the container lid being bolted on and the Arduino being mounted to the lid. The lower portion of the container features two flanges placed an inch apart that fit around the task tool tube. To secure it in place, the flanges have two sets of holes that bolts slide through, where they are tightened with a nut to lock the module in place on the tube. The power cable running from the Arduino to the power supply was taped down to secure it in place. The final assembly of the core mount with the Arduino and power pack can be seen in Figure 4.

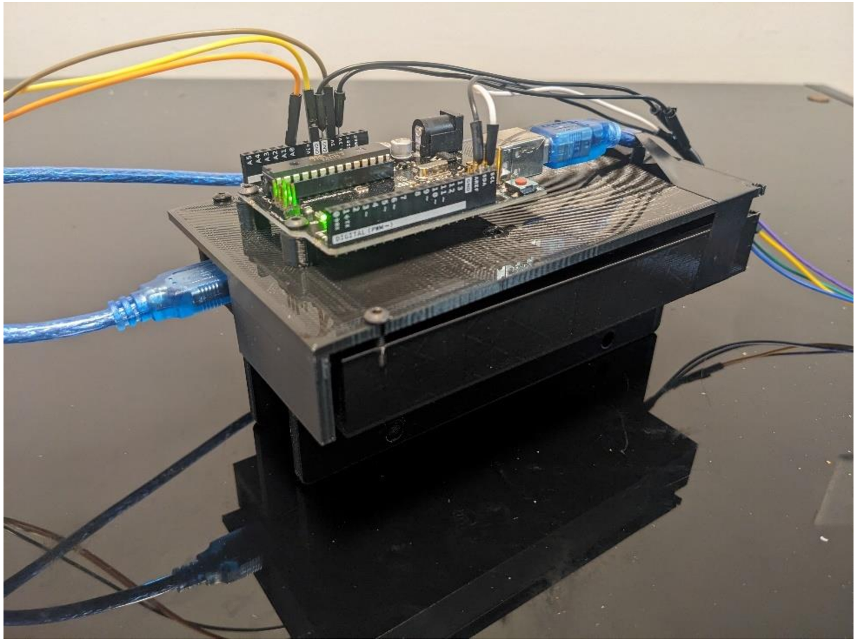

Figure 4. Arduino and Power Supply Mount

The next component that was designed was the LCD mount. This was a very simple component to design. The LCD being used already has mounting holes, so M2 bolts were used to secure the display to a 3D printed block. Small cylindrical spacers were printed to secure keep the display secured above the 3D printed component, and the bolts were then threaded into the block to mount it. To secure the full assembly, Velcro was used to allow for easy attachment and adjustment of the screen. Stuck to the back of the 3D printed component, the velcro wrapped around the tubing and interlocks with itself, removing the need to permanently place velcro on the task tool. Given the assembly is around 1”x3.5”, the velcro was more than strong enough to hold the display in place on the tube. The LCD mount can be seen in Figure 5.

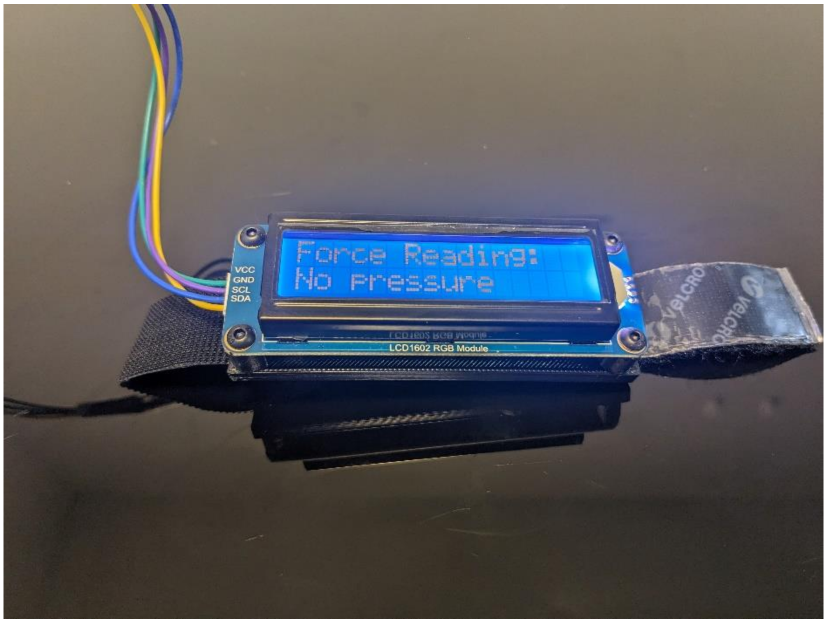

Figure 5. LCD Mount

The final component was the force sensitive resistor mount. This component was more difficult to design, as it needed to hold the small breadboard the force sensitive resistor is attached to, needs to be mounted on the gripper itself, and must be able to hold the FSR in position between the gripper jaws. The mount itself is fairly simple, consisting of a two-piece container bolted together with M3 bolts. The resistor sticks out one side of the mount, where it dangles down in between the gripper jaws. The FSR has velcro on it that sticks to the pad on the inside of the task tool jaws, holding it in position. The mount was held on using double sided tape, which makes it slightly harder to remove than the other portions but still acceptably simple. The mount can be seen in Figure 6, and the full assembly is shown in Figure 7.

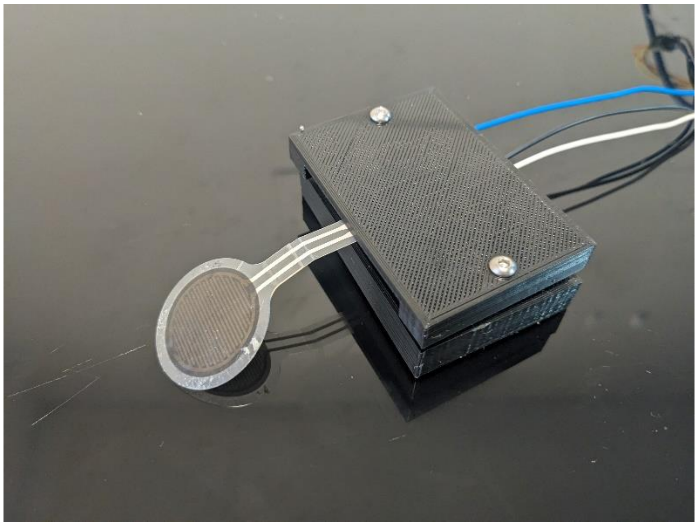

Figure 6. Force Sensitive Resistor Mount

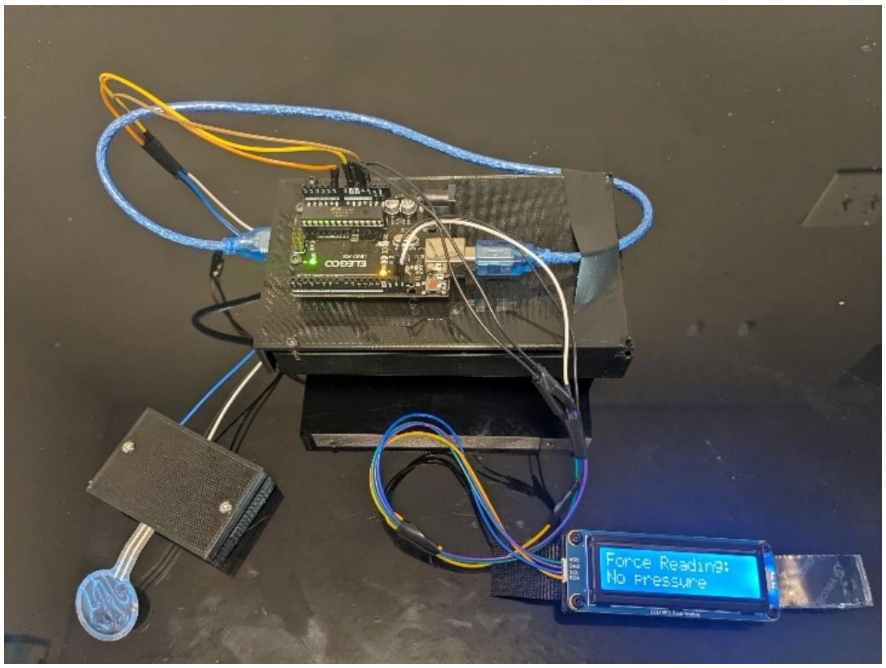

Figure 7. Fully Assembled Force Measurement Module

Once the mechanical design and assembly had been completed, the device was ready for testing on the task tool. This went fairly smoothly, with the 3D printed components fitting onto the tool where intended. One thing that was not anticipated was the fact that the task tool does not fully close. This meant that for a force measurement to be taken, there needed to be an object for the tool to grab. Through integrated testing, it was found that the measurement taken was highly dependent on the rigidity of the item being measured. In order for the FSR to properly record measurements, solid contact with an object that did not have any give was necessary. If the object being grasped was too soft or pliable, the sensor recorded a value that was far below what was expected, due to the lack of solid contact compared to the conditions it was calibrated in. Ultimately, this was worked around by using a 3D printed cylinder as the test object, as it provided a hard object that had solid contact with the sensor. The full assembly of the device on the tool is shown in Figure 8.

Figure 8. Force Measurement Module Installed on UAH Moonbuggy Task Tool.

Conclusion

Overall, the task tool force measurement module created in this project can be considered a success. The device created satisfies all the requirements specified in Table 1. The device can measure force output from the task tool up to 20 pounds of force applied. The attachment to the task tool was simple, with no permanent modifications needed. The task tool gripper remained functional, with the device not impacting use. With a total weight of under two pounds, requirement five was satisfied while maintaining a relatively low-profile design. Displaying output to the LCD screen was successful, and the module was fully self-contained, with no external connections needed for use.

However, the system has room for further development. Due to technical issues with the 3D printer used for the project, the mounting components did not come out as cleanly as intended and could use another iteration to improve the aesthetics of the module. The wiring when mounted on the task tool is another area of future improvement, as currently the wires are loose and could get caught on environmental hazards, even though they are secured well enough to not impact performance of the task tool under ideal conditions.

Perhaps the largest area of improvement would be the implementation of the force sensitive resistor. Through full system testing, it was found that the force sensitive resistor required very precise conditions to provide accurate measurements. The sensor was found to be thrown off when holding a soft or flexible object, as the force from the task tool would be transferred around the FSR rather than through it. This meant that very specific items have to be made available for accurate measurement of force output, which limits the practicality of the device. Additionally, the display only presents the applied force to the nearest pound, something that could easily be improved with further development. Ultimately, despite these areas for improvement the module proved capable of providing useful data for the verification of the task tool capabilities, marking the project as an overall success.

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