WESTERN MICHIGAN UNIVERSITY

College of Engineering and Applied Sciences

Depth of Calcination Meter

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ECE 4820 ELECTRICAL & COMPUTER DESIGN II

8 December 2020

Abstract

Gypsum wallboard is a common structural lining that consists of a core of gypsum (calcium sulfate dihydrate). Calcination of GWB is both a chemical and physical change that is caused by heating the board to temperatures that exceed 80°C (176°F). Currently, there are two methods used to measure the depth of calcification on heat treated materials. The first is to observe color changes by individually cutting cross-sections of gypsum wallboard. This method is timely and difficult. The other method would use a probe that measures the difference in physical resistance between the pyrolyzed and non-pyrolyzed wall sections and the other option. The need arises for a device to measure the depth of calcification directly. This device will take the human error out of the equation to measure the depth of calcification more consistently. The final design of the device utilizes a linear stepper motor, a stepper motor driver, two microcontrollers, and a glass scale. The two microcontrollers used are the Raspberry Pi Zero and the Teensy 4.0. The Raspberry Pi Zero controls the main operation of the device, as well as writing the result to the seven-segment display. The Teensy 4.0 handles the data going to the motor driver and from the glass scale. The resulting device has a simple to use interface, making testing much easier for novice fire investigators. The device only requires a button press to initiate the probing and once the probing is complete, the depth is displayed in millimeters to an accuracy of one one-hundredth of a millimeter. The measurement system has been found to be well within the required accuracy.

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PROJECT TITLE: Depth of Calcification Meter

PROJECT SPONSOR* Did this project have a sponsor? YES X (see footnote) NO____

Contact person and email address &/or telephone: Jason McPherson | jasonmcpherson05@gmail.com

Company Name: N/A

Design team has requested sponsor to verify in writing to course coordinator that all promised deliverables have been received. YES X NO____ (please check)

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Andrew Pates	Andrew Pates	12/11/2020

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The project was sponsored by Jason McPherson, an independent sponsor. All supplies and testing materials were supplied and or paid for by Jason McPherson.

Table of Contents

Introduction

Gypsum wallboard is a common structural lining that consists of a core of gypsum (calcium sulfate dihydrate). Calcination of GWB is both a chemical and physical change that is caused by heating the board to temperatures that exceed 80°C (176°F). When calcination occurs, around 75% of the water is chemically removed and the board becomes dehydrated [1]. At around 100°C (212°F) the gypsum in the GWB will chemically change from calcium sulfate dihydrate to calcium sulfate hemihydrate and at around 180°C (356°F) it becomes anhydrous calcium sulfate [1]. After calcination, the calcined portions of the GWB will experience a significant loss in mass therefore, a decrease in density. The decrease in density will be an important factor in measuring the depth of calcination.

An accurate and reliable approach to measurement is by using probe surveys, a method used by professional fire investigators for both depth of calcination and "depth of char" measurements for several decades [1]. The probe method uses a calibrate-like device to determine the depth of heat treatment by being inserted perpendicularly to the surface and measures the resistance (density) between the pyrolyzed and non-pyrolyzed, recording the relative amount of heat treatment. Comparing the relative depths of series measurements will indicate which areas have been more heat treated than others, helping to identify the source of the fire. Another approach is to observe color changes with individually cut cross-sections of the GWB however, this approach is more labor intensive, time consuming and involves perception of sometimes indistinct color changes, which can be altered by the process of cutting the cross-sectional areas, which can cause discrepancies with data collected by more novice fire investigators [1].

The probe method does incorporate similar subjective interpretations left to the discretion of the individual investigator however, it is still faster, more practical and considerably less time consuming and labor intensive. A significant aspect to the probe survey is both the accuracy and reproducible results and the difference in both the skill and experience of the individual investigator was determined to be insignificant to the accuracy of the results (i.e. lack of experience does not negatively affect the date). However, there is still a minimal training and practice that are needed for investigators to insure reliable and accurate data from the depth of calcination measurements [1].

Between 2011 and 2015, the U.S. fire departments responded to 358,500 residential structural fires per year causing 12,00 civilian injuries, 2,510 civilian deaths, and $6.7 billion in damages (NFPA statistics). The scene of the fires is investigated by origin and cause investigators with the goal of determining the origin and cause of the fire with outside assistance such as electrical engineers. Currently, there are two methods used to measure the depth of calcification for effected areas: a probe that measures the resistance (in this case, density) between the pyrolyzed and non-pyrolyzed wall sections and the other option is to observe color changes by individually cutting cross-sections of GWB however, this approach is more time consuming and experience. The need arises for a device to measure the depth of calcification to assist with the main goal of determining both the origin and cause of the fire. The current method uses a manual depth gauge that is very prone to human error. This device will take the human error out of the equation to more consistently measure the depth of calcification.

The following is a report on the design, building and evaluation of a depth of calcification meter. This depth of calcification meter is easy to use and accurate. This project is sponsored by Jason McPherson who has given aid in the form of guidance on the topic and money for the components. In addition, Mr. McPherson has offered some literature to help in the research process as well as the samples that the device was tested on. The specifications for this project are given in table 1.

This report consists of five sections. The next section goes over the specifications required for the design as well as the results of a feasibility study. Section three will cover the design of the device. The fourth section will go over the testing results of the device. The schedule of the project and member skill requirements will be discussed in the last section.

Feasibility and Specifications

In-depth list of device specifications

Table 1 contains the list of specifications and components that are to be designed. In addition, each item is marked as either a requirement, goal or preference as indicated in the second column.

Table 1: List of Specification to be Designed	
1. *Hardware*	
1.1. Microcontroller	
1.1.1. Controller must be able to accept analog and digital inputs.	R
1.1.2. Controller must be able to interface with an LCD screen.	R
1.2. Constant Force Application	
1.2.1. Force application system will utilize a linear actuator to apply a constant force to the probing tip.	R
1.2.2. Applied force should be consistent between samples.	G
1.2.3. Applied force should be between 27N and 31N.	R
1.2.4. The probing tip must be between 3 mm^2 and 3.2 mm^2.	R
1.3. Displacement Sensing	
1.3.1. The device will sense displacement by utilizing a LVDT mounted to the force applying mechanism.	R
1.3.2. The sensor must be accurate to at least 0.5 mm of depth.	G
1.3.3. The probe must be able to extend to a distance of 15 mm.	R
1.3.4. The sensor must have calibration capabilities so that the zero point is flush with the surface of the device.	G
1.4. Power Source	
1.4.1. The device will be powered by a battery pack.	P
1.5. Structure	
1.5.1. The device must be contained in a handheld container.	R
1.5.2. The device must have a large flat surface on the applied side.	R
1.5.3. The device must have two handles that are graspable with gloves	G
2. *Software*	
2.1. Software must be programmed to accept analog data from LVDT.	R
2.2. Software must be capable of updating an LCD screen.	R
2.3. Software must be able to log and retrieve data.	R
3. *Reducing Budget Spending*	G

Project Deliverables

This section of the proposal covers the promised deliverables of the prototype, to be completed by the 13-week deadline.

1. A working prototype of the handheld device.
2. Bill of materials
3. User manual
4. System specification
5. Schematic diagrams
6. Commented code

Input

The primary input of the system is the depth of the calcification layer that is produced from heat treatment on gypsum wallboard. This layer is caused by chemical and physical changes in the wallboard when it is exposed to temperatures in excess of 80°C. The resulting material is less dense than the original gypsum wallboard. This facilitates the measurement of the calcification layer by the force required to puncture different depths. The calcification layer can vary from 0 mm to 14 mm in depth [1]. If a probe that has a flat surface with an area of about 3 mm^2 is used, then the force required to penetrate the calcified layer does not exceed 2.7 kg force or about 26.5 N [2]. In addition, the minimum force to puncture the unchanged material behind does not fall below 4 kg force or about 3.9 N [2].

The LCD (liquid crystal display) screen should have a resistive touch input capability. The primary purpose of this is to ensure ease of use and comfort when reviewing the logged samples. The touch screen will be used to access the log of data and browse the data in the log. Additionally, the touch screen may be used to access a menu where the user can change settings.

The user must also be able to interact with the system while their hands are covered while in the field. It is for this reason that there must be physical buttons accessible by the operator of the device. The processes to be controlled by buttons are initiating the probing process, logging data, browsing logged data and calibration. One button will be pressed to start the probing process and another press will cancel the process. Three buttons will control the data logging. One of these will store data when pressed if the user approves of it and another input method, perhaps a long press, will allow the user to access the log. Two other buttons will act as navigation while the log is being active. Lastly, before use of the device, calibration will likely be necessary. A single button will begin the calibration process when pressed. In addition, a switch will be implemented to power the device.

Output

The main output of the system will be the LED display. Here the user should be able to see the most recent result as well as the number of logged results. Also, some extra data may be provided here as deemed necessary during development. There should also be an indication to the user that the probe has reached the end of the calcified layer.

This could be an LED (light emitting diode) on the device or an indicator on the LED display.

A secondary output of the system will be the data logged while in the field. The device will use a USB (universal serial bus) port that will accept a storage device with the interface of USB type A. Once a device is connected to the port all the data from the last logging session will be copied to a folder with the current date. Data will not be removed from the device until the user deletes it using the LED display.

Economic Feasibility

The economic costs have been calculated without considering the cost of shipping & handling. Values have been rounded up to simplify the final cost calculations.

1. Mechanical linear actuator - $110
2. Linear variable differential transducer - $120
3. Rechargeable LiPo batteries - $50
4. Raspberry pi - $35
5. LED display - $30

Safety Precautions

1. Proper safety precautions must be incorporated to ensure safe and reliable charging of the batteries.
2. The force of the probe must not be able to do harm in the case of malfunction.

Acceptance Testing

Test for the accuracy of the depth measuring system:

1. Twenty samples of gypsum wallboard with known calcification depth from the caliper probe test will be used for testing.
2. The device will be calibrated by placing it on a hard surface and pressing the calibration button.
3. The samples will be probed by the device one after another and the measurements will be logged.
4. The logged data will be judged against the caliper method and the device should output the correct depth, in mm, 95% of the time
5. The effects of repeated measurements will also be evaluated by comparing the accuracy near the beginning of the test to the accuracy near the end.

Test for the accuracy of the force application:

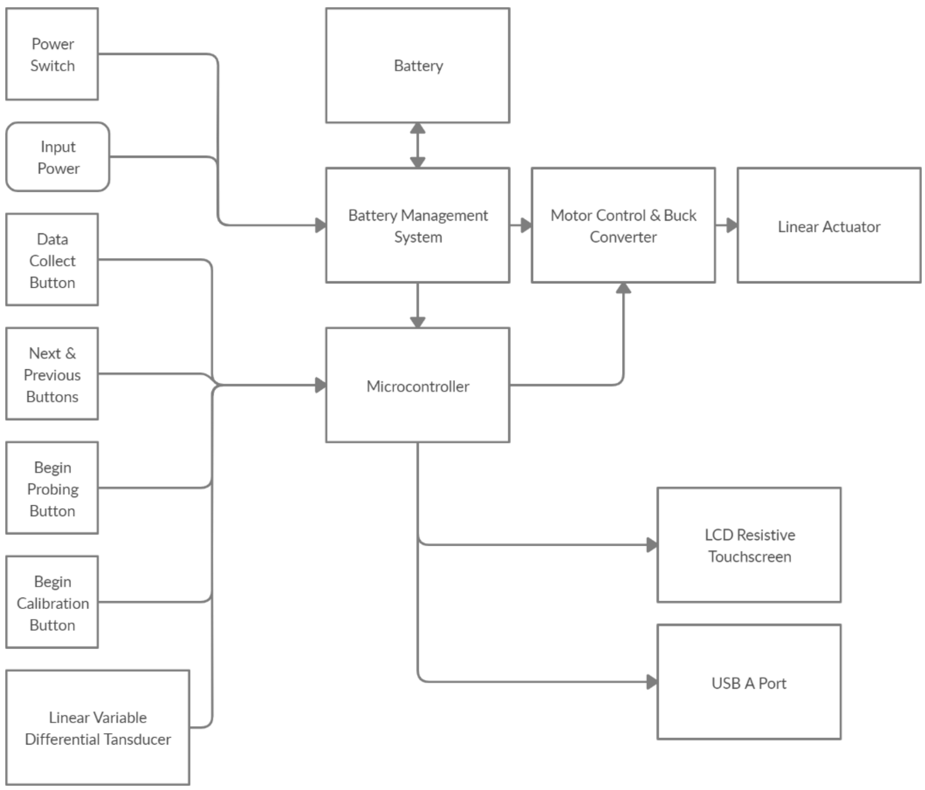
1. An accurate force sensing device must be acquired and a mount for the device must be made.
2. The mount must allow 5 mm between the applied surface of the device and the force sensing device.
3. The probing sequence will be activated on the device as though a normal sample was being taken. The probe will be allowed to make contact and apply force to the sensing device.
4. The maximum force that the probe applies to the force sensor will be recorded.

Design and Implementation

Initial Overview

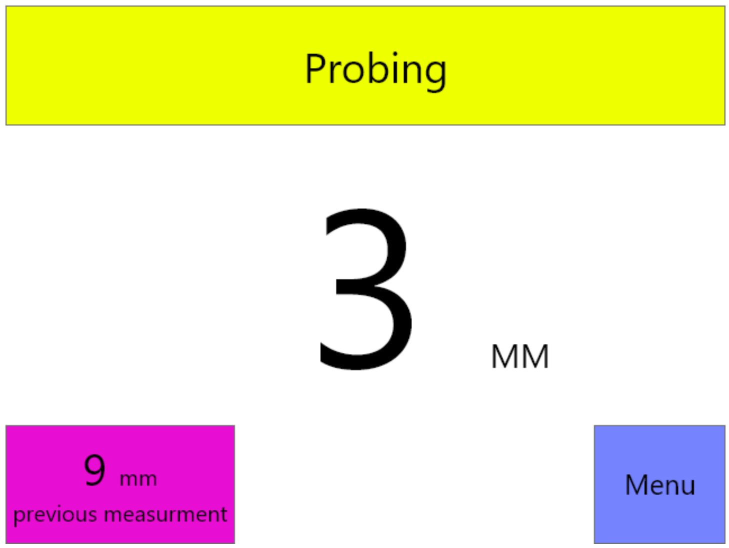
Figure 1 is a block diagram that represents the connected systems of the device. At the center of the diagram is the microcontroller.

Figure 1: Initial Block diagram



The inputs of the microcontroller will be an LVDT (linear variable differential transducer), an LCD resistive touch screen and several buttons. The LVDT will be the primary sensor for detecting probe displacement. The display will have a simple user interface, which can be seen below in Figure 2. The outputs of the system are the LED display and the USB port. The screen will display the measured data as well as additional information. The USB port will give the device the ability to store the logged data onto a separate device.

Figure 2: LCD UI Mockup

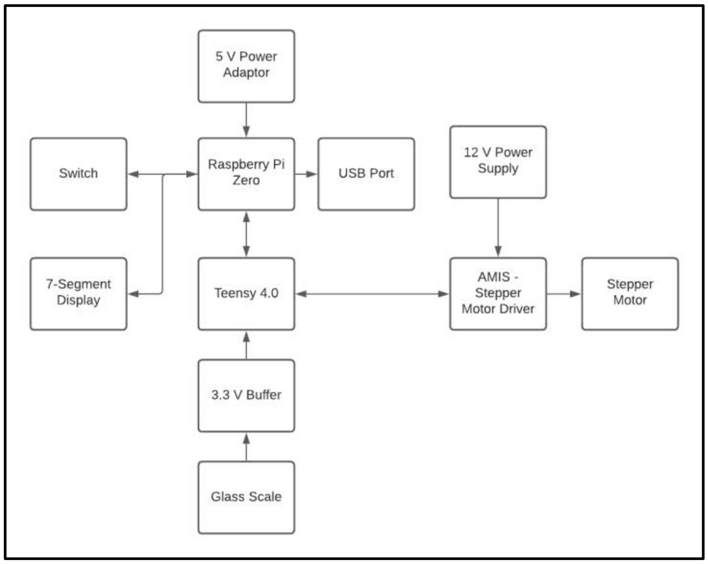


The linear actuator will provide the constant force that will drive the probing tip. This will be attached to the LVDT to measure displacement. A motor control drive will be used if the actuator needs additional circuitry.

Because the device is handheld, it should be powered by batteries. The batteries should be able to keep the device powered for 4 hours. A BMS (battery management system) will be used to ensure the safe charging and discharging of the battery.

Overview of Implementation:

Figure 3: Block Diagram of Final Design



Patent Search:

A patent search is also being conducted. At this time the search has resulted in no patents for any similar devices that can be found. Search terms used are: <u>Automatic, Gypsum, wallboard, fire, investigator, calcification, measurement.</u> Our sponsor was also contacted about this issue.

Microcontroller Plan:

The microcontroller that will be used is a Raspberry Pi. This device provides us many options on how to program the device and many options for LED displays. As mentioned above, the LED display that will be interfaced with the Raspberry Pi will be a resistive touch screen. This resistive touch technology is vital because this device is to be used in hazardous environments and such will be used with gloves.

The Raspberry Pi has many GPIO (general purpose input output) which will be more than enough for the several buttons that we plan on including. We plan on using five buttons and that should be easy to implement on the Raspberry Pi [3]. We may create a PCB (printed circuit board) to connect all the buttons and other accessories conveniently in one place that may make it easier for production if the device were to be produced.

The programming language that will most likely be used is Python as it is the seems to have the most examples written for the Raspberry Pi. Python is also very easy to write and understand for the average person. Another alternative would be C, this has the benefit of speed and direct memory control if needed, at the sacrifice of ease of programming and readability.

Microcontroller Implementation:

The implementation of the microcontrollers was a dual microcontroller system. A Raspberrypi Zero W was used as the main device and was used to overall manage the system. A teensy 4.0 microcontroller was then also used to directly control the stepper motor driver and interface with the linear glass scale.

To begin, the Raspberrypi Zero W was used in contrast to the larger and more expensive versions of Raspberrypi’s primarily because of that lower cost and smaller size. The Raspberrypi Zero W (RPi) directly communicated with the 7-segment display over a I2C interface with the data that it receives over a serial communication with the teensy microcontroller. The RPi also receives input from a button which if it is pushed for > .1 seconds or < 2 seconds it sends the command “9\n” to the teensy microcontroller which instructs the microcontroller to probe, whereas if the button is pushed for > 2 seconds the command “24\n” to the teensy which instructs it to set the current position of the probe to zero. Finally, with the received data it is saved to a .CSV file with the date of the probe measurements as the file name.

The teensy microcontroller handled all critically timed actions, and therefore the RPi was not used as the RPi is a not a real-time system and therefore cannot guarantee precisely timed signals. The teensy communicated with the stepper motor driver over a SPI communication and two digital pins. The SPI communication was used to set things such as drive current of the motor and micro-stepping. The two digital pins were used for step and direction, step is a precisely timed output that pulses when the stepper motor is to take its next step and direction is high or low based upon which direction the motor should be spinning. The other connection the teensy had was with the linear glass scales where it counted the pulses from it and stored that in its dynamic memory until it was time to send it, the value would be divided by 200 and then sent to the RPi over the serial interface.

Force Application Plan:

The force applied to the probing tip will be controlled by a linear actuator. The actuator will be housed inside of the device and will allow the probing tip to extend out of the device. The microcontroller will control when the actuator extends and retracts. A specific linear actuator has not been chosen at this point, but the requirements of the actuator are known.

The actuator must have a stroke that is above 15 mm because that is the deepest calcification goes [1]. The chosen actuator is planned to have a maximum stroke length of about 20 mm.

The amount of force required is always constant but relatively precise. The applied force needs to be between 27 N and 31 N [2]. This is to ensure that the probing tip punctures the calcified layer of the gypsum wallboard but does not penetrate the unchanged material. It is unlikely that an unmodified linear actuator will meet the force need exactly. This can be fixed by modifying the input. The torque output of a motor is linearly proportional to the current input. Additionally, because the required force does not change over time, the input can be controlled to a specific value. The current to torque ratio of any motor depends on that specific motor. Because of this, a specific controller cannot be designed. However, it is known that a buck converter will likely be used.

Force Application Implementation:

Our implemented force application method was a NEMA 17 stepper motor attached to a threaded shaft with a nut. This nut is then bolted to a carrier that attaches to the carriage of the displacement measurement device and the probe itself. This NEMA 17 stepper motor was driven by a AMIS-30543 stepper motor driver. To apply the proper force on the calcified wallboard we calibrated the force output of the motor by current control against measurements that were taken by hand. We are confident in the consistent output of force on the probing area but did not have the resources to measure the exact force in Newtons. The stroke length of the device is also well long enough, it could possible be up to 100mm or even more with a longer probe and slight modifications to the code.

Displacement Measurement Plan:

The displacement of the probing tip will be measured by an LVDT that is physically connected to the linear actuator. When the actuator pushes the probing tip into calcified material, it will stop at the uncalcified material due to insufficient force. At this point the microcontroller will record the input value from the LVDT and convert it into millimeters. The LVDT was chosen due to its accuracy in measurement and its ability to be implemented on this small scale. While a potentiometer could have been used, an LVDT is already suited for linear displacement measurement. The drawback of the LVDT is the fact that it needs an AC signal in order to operate [4]. This means that the sensor will require additional circuitry to facilitate this. In addition, the LVDT that is chosen must have a stroke length that meets or exceeds the stroke length of the linear actuator.

An alternative to the LVDT is the resistance-based linear displacement sensor. This option is cheaper and easier to implement due to the simplicity of the design. This alternative will not require an AC signal to operate and the output will also be in DC. The possible drawback is less precision. If this device does not meet our accuracy requirements, then it cannot be used.

Displacement Measurement Implementation:

As we investigated further price to performance ratios for LVDTs we discovered that that ratio was not very good. Further into research it was found that quadrature-based linear glass scales offered extremely good price to performance ratios. This is the device that we implemented into our design. To operate them you apply 5V and GND to two of the device's pins and then as the carriage moves across the glass scale it outputs two offset pulses so that you can determine distance moved and direction. This is well shown in the below diagram. Our glass scales that were implemented have an output of 200 pulses per mm, this gives a resolution of 0.005mm.

Figure 4: Encoder Output

```
                           _______         _______
              Pin1 ______|       |_______|       |______ Pin1
negative <---          _______         _______         __      --> positive
              Pin2 __|       |______|       |______|    Pin2
```

Power System Plan:

The device will be handheld and therefore the best option for powering the device will be batteries. Our selection for a battery is a LiPo (lithium polymer) 4S battery pack. It is unknown how large it is required for this battery to be because the exact power requirements of the device are not yet known. However, it is estimated that the device will draw 800 mA at its peak.

The battery must be protected in its regular use. A BMS will be used for this reason. The BMS must be able to control the safe charging and discharging of the battery. In addition, the BMS must have protective circuitry to protect the battery and prevent a potentially dangerous failure.

Power System Implementation:

Instead of a battery-based system we opted for a corded approach. After conferring with our sponsor, it was determined that to save time and budget this corded approach should be suitable for a prototype. The system that was implemented required 2 different power supply voltages and unfortunately this required then two separate power supplies with two separate cords. While this did not meet our original ambitious goal of designing a power system for the device, the cords are fine for this early prototype that can be expanded upon in the future.

Structure Plan:

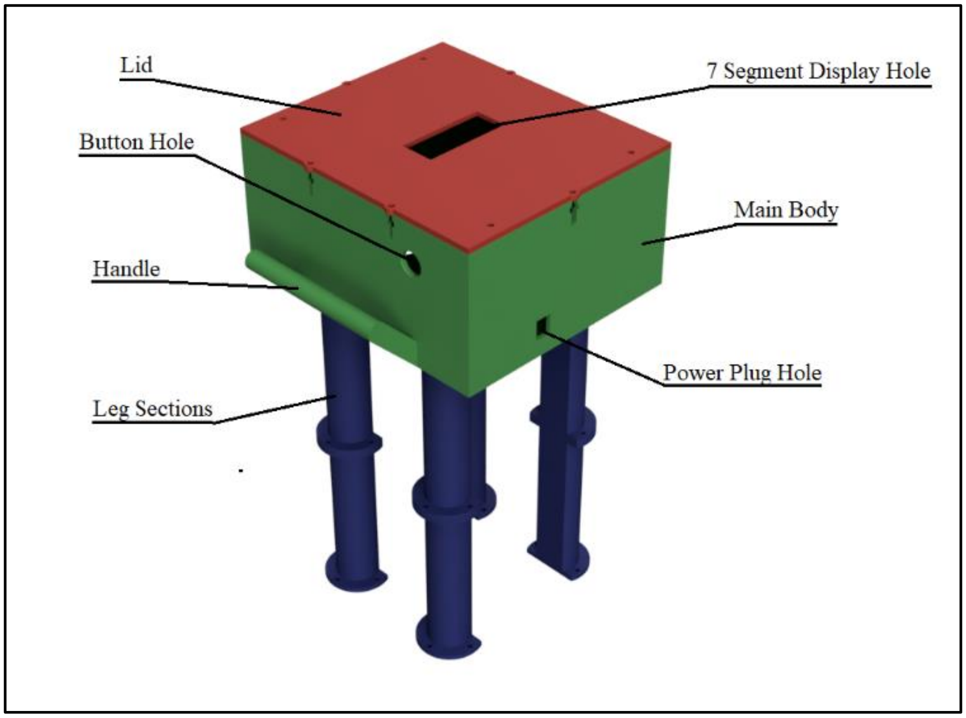
The device should be light enough to lift above the head as calcification depth test must be done on ceiling as well as walls. The applied surface of the case of the device is going to be broad and flat. The first reason for this is the fact that the operator will be applying force to the device against the calcified surface and having the devices surface be large will help distribute the force. Another reason for the large, applied surface is to ensure that the probing tip is perpendicular to the layer of calcification.

While the user facing side of the device has fewer physical needs, it will require two handles on either side. In addition, there must be room for the LED display and the buttons. Internally, there must be room for all the required electronics. Another consideration is the fact that the user must be able to start the probing sequence while holding both handles. Because of this, the probe start button must be reachable from one of the handles. Perhaps the device should have one of these buttons on either side.

Structure Implementation:

The structure of the device was finalized as several 3D printed components that were then bolted together with M3 machine bolts + nuts. A labeled diagram of the CAD model can be seen in Figure 5 below. There are 8 leg components which are connected in pairs then attached to the main body of the device. These leg sections can be identified as the blue colored section in Figure 5. Next is the main body of the device. This is the part that holds all of the electronics and the main circuit board. The main body has the handles and position for the button as outlined in the plan. The main body is the green section of the diagram in Figure 5. Lastly, is the lid component. The purpose of the lid is to cover the electronics and also give a spot for the seven-segment display to be. The lid is the red section in Figure 5.

Figure 5: Labeled Diagram of Cad Model



Results

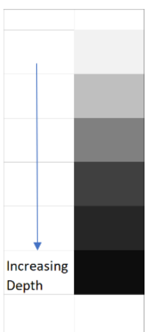
The device was tested by probing a sample given by Mr. McPherson. The samples were divided into roughly 2 inch by 2 inch sections and a probe was taken at the center of each section. This was done to two different boards. The results of these tests were put into spreadsheets which can be seen in Figures 6 and 7 below. The samples given were not tested beforehand so the results had to be verified by the students. Verification was done by inserting a probe into the hole made by the device and measuring the depth with calipers. In addition, tests were done using the current probe method by hand. The results of these tests are inconsistent due to the lack of experience of the students and inherent variability in the method.

As can be seen from Figure 6, the first board has lower average values. This would indicate that it has received less heat than the other board. This fact has been verified by the sponsor, who heat-treated the samples. The bottom row of the board gave very small results which would indicate that it has received little to no heat treatment. On the surface of the board, there is a clear visual change around this section of the board. It is likely that this section of the board was blocked from the heat during the heat-treating process.

The second board can be seen in Figure 7 below. This board has deeper average results compared to the first board, as noted previously. Of interest on this board, are the areas of deeper results. This data would indicate that these sections of the board received more heat-treatment for one reason or another. Interestingly, these sections of the board are not very visually distinct from the other areas, so this conclusion could not have been come to without the probing method. Similar to the first board, there is one very shallow data point on the second board. This is likely due to the one spot being coved during the heat-treating process. As with the first board, this spot is also visually distinct from the regularly heat-treated areas.

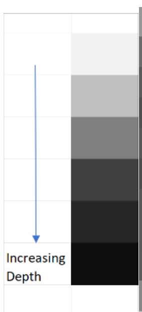
The verification process of the device consisted of re-probing the holes made by the device and measuring the depth with calipers. This process is very imprecise due to the inaccuracies of the human eye. These tests only aimed to achieve about 0.5 mm of accuracy, as noted earlier in the report. The results of these tests showed that the device came within the desired threshold every single time that the verification was taken. However, these results should not be taken as absolute due to the inaccuracy of the verification. Further testing by experienced professionals should be carried out.

Figure 6: Testing Results of First Board



1.62	2.77	3.79	5.22	5.70	6.48	6.79	5.81	5.75	5.97	5.41	5.65
2.48	4.04	5.11	5.68	6.57	6.54	6.99	7.04	7.14	5.22	5.78	5.14
2.92	3.98	5.06	5.98	6.25	5.61	6.50	6.42	6.46	6.55	5.88	5.99
3.72	4.50	5.50	5.83	6.51	6.49	6.88	6.83	6.77	6.56	5.72	5.68
3.87	4.02	5.34	5.68	6.21	5.48	6.64	6.60	6.58	6.47	6.09	5.64
3.52	4.13	4.93	4.92	6.08	6.50	6.70	6.51	6.58	6.28	6.21	5.46
3.85	4.08	4.72	5.36	6.04	5.99	6.32	6.50	6.32	6.05	5.76	5.64
3.28	3.70	4.39	4.67	5.62	5.76	5.71	6.25	6.11	5.92	5.45	5.41
2.46	3.62	4.20	4.90	5.17	5.59	5.28	5.62	5.34	5.44	4.96	4.97
2.19	2.97	4.20	4.73	5.37	5.45	5.67	5.63	5.69	5.08	4.63	4.47
2.57	2.83	4.50	5.49	5.98	5.03	6.20	5.55	5.47	5.16	4.58	4.59
0.00	0.00	0.00	0.00	0.45	0.30	0.59	0.46	0.20	0.47	0.80	0.84

Figure 7: Testing Results of Second Board



3.45	4.64	5.31	4.93	5.53	5.25	4.32	4.66	4.2	3.97	4.04
5.32	5.42	5.87	6.16	5.88	5.86	5.5	5.41	5.01	4.21	4.09
6.07	5.63	6.12	5.92	5.51	6.02	5.95	5.08	5.98	5.64	5.52
6.54	6.55	6.55	5.75	6.42	5.8	5.9	6.45	5.66	5.62	5.79
6.21	7.16	6.46	7	6.63	6.22	6.3	6.7	6.18	5.75	5.24
6.58	6.81	6.65	6.67	7.2	7.19	6.68	6.39	6.05	6.23	5.25
6.24	6.72	6.75	6.76	6.21	6.41	5.87	6.39	6.82	6.71	5.91
6.12	6	6.57	7.07	7.01	7.21	7	6.76	6.8	7.45	6.19
6.07	6.45	6.72	6.46	6.8	7.03	6.46	6.04	7.02	6.87	4.79
4.2	4.81	5.09	5.26	4.98	5.12	4.89	4.95	4.51	5.92	0.16
1.98	3.9	4.75	4.96	4.92	4.54	4.16	4.28	4.14	4.08	3.96

Bill of Materials

The final bill of materials can be found in Table 2 below. As can be seen, the total cost of materials used in the device comes up to be $278.38. This is well below the estimated budget of about $350. This is largely due to the change from a LDVT to a glass scale. The price of the device could be driven further down by using a simpler stepper motor. However, more research would have to be done as to the most simplistic motor that would be acceptable.

Table 2: Bill of Materials

Item	***Cost***
Stepper Motor w/ Lead Screw and Nut	$ 137.36
Linear Glass Scale	$ 39.97
4-Digit 7-Segment display	$ 9.95
Raspberry Pi Zero W	$ 10.00
USB Extension	$ 6.31
USB Hub	$ 5.99
USB Power Adapter	$ 13.90
Stepper Motor Driver	$ 14.95
3D Printer Filament	$ 30.00
12V Power Supply	$ 9.95
Total	$ 278.38

Schedule

The schedule for designing and building the prototype has been broken into three different sections. The first section covers the critical path of the design, the second section covers the precedence matrix and the final section covers the Gantt chart. All three sections together layout an efficient path to successfully completing the prototype within a 13-week deadline.

Precedence Matrix

The precedence matrix layouts the priority of each section of the project. The parts are marked by their dependence on other sections of the device. The resulting matrix is below in Figure 3.

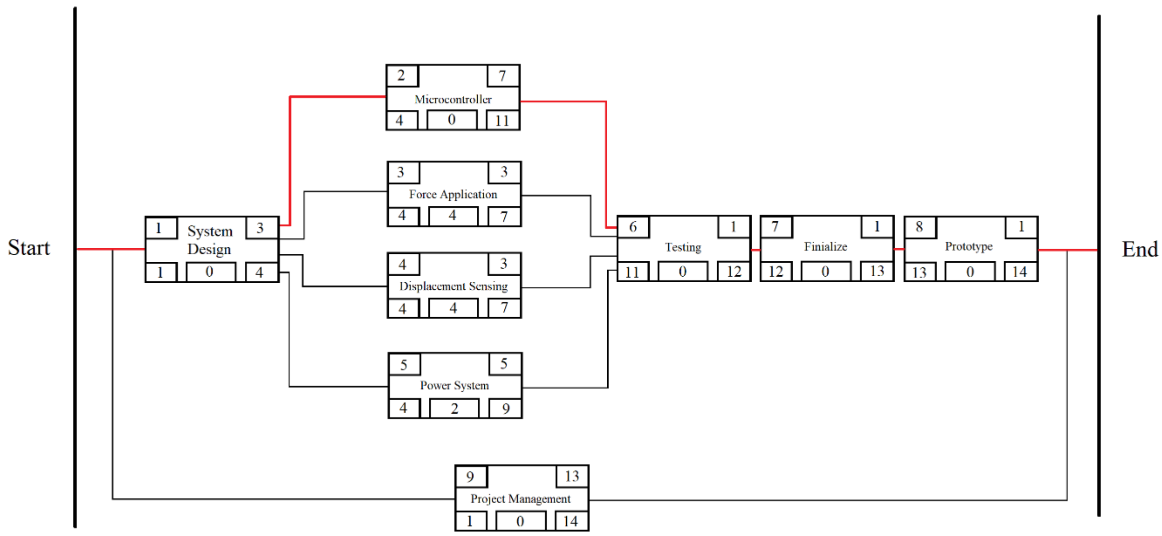
Figure 8: Precedence Matrix

		a	b	c	1	2	3	4	5	6	7	8	9	10
a	Accuracy of measurement	x												
b	Consistantcy of pressure		x											
c	Data Logging			x										
1	Microcontroller			H	x		M				H			
2	LCD Display				H	x	L							
3	Interface buttons						x							
4	Linear Actuator		H				L	x		H				
5	Probing tip	H						M	x					
6	Actuator Control		H							x	H			
7	Sensor Circuits	H									x			
8	Linear Transducer	H			M						H	x		
9	Battery												x	H
10	BMS													x

Critical Path

The critical path can be seen in Figure 4 below. The diagram has been built based on the precedence matrix and has an emphasis on efficiently for completing the prototype within the deadline. The critical path is marked by a red line.

Figure 9: Critical Path Diagram



Necessary Group Experience

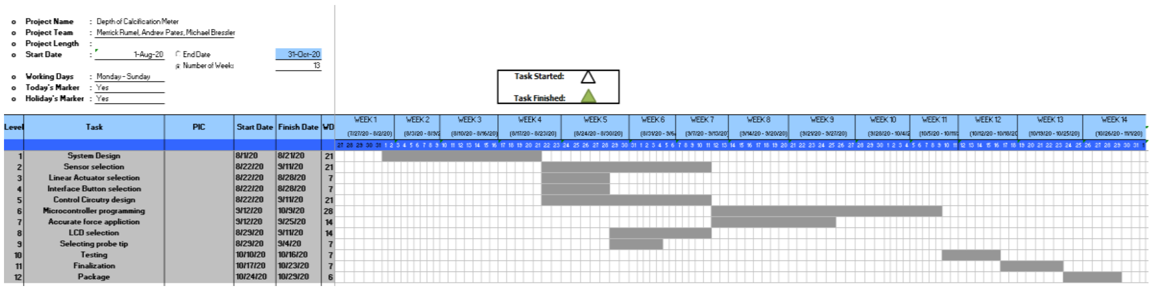
Table 3: Project Requirements and Relevant Experience

Technology	Associated Class	Group Member(s) with Relevant Experience
Microcontroller	ECE 4510 Microcontroller Applications ECE 2510 Intro. to Microprocessors	Merrick Rumel Andrew Pates, Michael Bressler, Merrick Rumel
Circuit Design	ECE 4200 Power Electronics ECE 2210 Electronics 1 ECE 3300 Electrical Machinery ECE 3200 Electronics II	Andrew Pates Michael Bressler, Andrew Pates, Merrick Rumel Andrew Pates, Michael Bressler Andrew Pates, Michael Bressler
LCD Display	ECE 4510 Microcontroller Applications	Merrick Rumel
Actuator Control	ECE 3710 Linear Systems	Michael Bressler, Andrew Pates, Merrick Rumel

Gantt Chart

The Gantt chart provides detailed description of the scheduling. Notice, the grant chart begins the project starting August 1, 2020 and finishes November 30, 2020. The Gantt chart still coincides with a 13-week schedule starting from September and ending in December. Due to the size of the Gantt chart, it will be included with this report as an attachment.

Figure 10: Gantt Chart



Conclusions

The result of this project is a device that probes into calcified gypsum wallboard and measures the distance the probe goes. The main device consists of a linear stepper motor, a stepper motor driver, two microcontrollers, and a glass scale. In addition, a CAD model was developed to contain the device. This model was then 3d printed and this print acts as the devices structure. The device also utilizes a button and a seven-segment display to aid the operator in the use of the device.

The ending design is different from the initial conception. However, the core concept of a probing sequence with a constant force and measuring that displacement is still intact. When the implementation phase began, the force application device was changed from a normal brushed motor to a linear stepper motor. Also, instead of active force monitoring, the density difference was detected by making the motor stall. The motors max force was done by limiting the current that goes to the motor. As for displacement measurement, the design changed from using an LDVT to using a linear glass scale. This is a much more attainable option, and the microcontrollers can use the data it gives to accurately track the motion of the probe. In addition, another microcontroller was added to help control the motor and accept data from the glass scale.

The results from testing the device are promising. The device can quickly take samples from different parts of a wallboard. In addition, the device is decently consistent. Also, verification tests have shown that the displacement measurement works very well. The only aspect that cannot be verified how close the probe is to the actual calcification depth. This is because the samples given were untested and the only verification that could be done was done by the students.

Appendix

Works Cited

[1] P. Kennedy, K. Kennedy and R. Hopkins, "Depth of Calcination Measurements in Fire Origin Analysis," in *Fire and Materials*, San Francisco, 2003.

[2] C. L. Mealy and D. T. Gottuk, "A Study of Calcination of Gypsum Wallboard," in *International Symposium on Fire Investigation Science and Technology*, Sarasota, 2012.

[3] Soren, "Using a push button with Raspberry Pi GPIO," 18 Febuary 2018. [Online]. Available: https://raspberrypihq.com/use-a-push-button-with-raspberry-pi-gpio/.

[4] OMEGA Engineering, "What is a Linear Variable Differential Transformer," 29 August 2018. [Online]. Available: https://www.omega.com/en-us/resources/lvdt-sensors. [Accessed 12 April 2020].