Plasticity Modeling

Final Report

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2017-2018

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EXECUTIVE SUMMARY

The purpose of this report is to design an experimental device used by Dr. Feigenbaum, which will help visualize the elasticity theory. The device will measure the force applied to a box that works in both tension and compression. It will also measure the displacement of the box on a frictional surface. The device will be connected to a computer and by using a software it will display force vs. displacement for both x and y direction. A potential resistor will be used to give an accurate reading of the force applied. An Arduino Uno board will be used as the heart of the sensors that are attached to the box, it will measure the displacement. The sensor measuring the displacement will be a CMOS sensor, which we extracted from an optical computer mouse. The overall design will be module, where springs can be added or removed by the user. The box itself should be heavy enough to stretch the springs before it starts to move. An Arduino Uno board is used to connect all the sensors together. A code was written to program the block to output data in a clean visible way. The team used PLX-DAQ program to export the digital data to excel where it's customizable by the client. The client is then able to add formulas, columns and most importantly graphs. The device will be portable and customizable, easy to use by the client and her students. This project will be used by Dr. Feigenbaum's graduate level students and hopefully be used by universities across the country.

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1. BACKGROUND

This section will be an introduction to our project. Which is a block that slides over a frictional surface along X & Y directions, when the force is applied to the box, it should simultaneously display a Force vs. Displacement graph with the direction of motions. There are two of equations being used especially with the kinematic equations as we need to get an F (u, v) vs displacement graph at the end of the demonstration process.

1.1 INTRODUCTION

In this capstone course, we are challenged to work with Dr. Feigenbaum on developing a classroom aide for advance plasticity. It's basically a plastic box model that moves in both X & Y directions. The design should be able to demonstrate the elasticity theory for students. So, our design should be creative with the idea and easy to deal with for all students. In order to teach the students, the elasticity theory, we will attach the sliding box with a spring and whenever the student applied a tension or compression on the spring it will immediately graph an output for force vs displacement on both directions. Now student should be able to clearly understand how the elastic limit behaves. This project will benefits Dr. Feigenbaum and her students the mechanical engineering department they are our primary stakeholders.

1.2 Project Description

This is an educational project that helps Dr. Feigenbaum's teach elasticity theory. In this class students should be able to demonstrate Force Vs displacement by either to plotting the data or graphing through Excel. We are going to build a box with different surfaces and attach a block with a free springs and springs that are connected to the fixed frame. This demonstrates to the students the behaviors elasticity theory. Students will be able to switch around the springs until they get the exact graph looking. The design should be a desktop sized, small enough to be stored in her office, and seen in the classroom of 20 students and be cured without extra help.

To explain the operation of our project it will see the displacement cover when the force will apply. The displacement will cover in 2D one is x-axis and second is y-axis. So, the operation is that the box will slide through a force and it will cover a distance because of sliding and friction will hold the box until the spring will deform.

$$F = F_x i \ + F_y j \qquad (1)$$

$$U \ = \ u_x i + u_y j \qquad (2)$$

With the above equations we will do the plots. So, the graphs that will make at the end of this operation will be for force vs. displacement in both x direction and y direction.

1.3 ORIGINAL SYSTEM

Purpose of this project is to build a tabletop model in order to find the plastic and elastic-plastic materials behavior. As the project requirement is to build such system so basically it is an Original system. The project involved the design of a completely new elastic behavior model using the sliding box and spring system. There was no original system when this project began.

Dr. Feigenbaum will use this device to explain how the material behaves after the elastic limit. In this model a spring will connect to the box from one free end and the other end of spring connects with the fixed support. The box is connected to a spring, is on frictional surface, where the box has resistance when sliding over the surface. Surface has some sort of friction and slider box can slide over it easily with the help of spring to move to and fro over it. In order to understand the behavior of material after the elasticity then multiple frictional surfaces will use to test, and multiple size of boxes will use and multiple type of material will use for the box. There will multiple type of springs will use with different stiffness in the spring. Through this project we will determine the deformation caused by the force and see how much deformation appeared. Force vs. displacements will measure for it.

2. REQUIREMENTS

The design that we are going to build is going to be used by students who are taking advanced classes for plasticity with Dr. Feigenbaum. This section will include the customer requirements, engineering requirements, testing procedures and house of quality a few difficult because we must give our client a design that will grab the attention of her students in the classroom.

2.1 CUSTOMER REQUIREMENTS

The team generated Table 1.1 after meeting with the client, who talked about the overall function and the constraints of the device. She made it clear that she wanted the device to be visible to a whole classroom, but also lightweight and easy to carry. The table below summarizes her requirements and the description of each one.

Table 1.1: Customer Requirements

Customer Requirements	**Description**
Desktop sized system	It means a small to medium design device. Basically, it's going to be around the standard size table.
Large to seen in the classroom of 20 students	Design with a good shape, so that all the students in the class can see how the design work is.
Small to store in an office	Good size that is not large or heavy so she can hold it with other help and can fit directly to the client's office.
System will be controlled by the user	A force exerted by the student and that force will be the output springs.
Work in both tension and compression	Can handle the forces exerted by the user.

Light weight	The device must be easy to carry by the user.
Plotting force vs. displacement	Arduino with the force gauge connected to the display to show graphs.
Multiple frictional surfaces	Means by multiple users.

2.2 Engineering Requirements

From the customer requirements, the team generated a list of engineering requirements that will satisfy the client's needs. These requirements focus on the actual components of the system and their targeted values. These values will help select the design, implement the design ideas, these targeted values will be in mind to make easy to develop different ideas and to select the final design on the basis of these requirements and targeted values. Engineering Requirements for the project are listed below in Table 1.2.

Table 1.2: Engineering Requirements

Engineering Requirements	**Targeted values**
Max Spring Expansions	0.15 m
Elasticity	0.5 m
Pushing Pulling Force	10 N
Frictional Factors	1
Weight of system	18 Kg
Length of Sliding Area	0.5 m
Wireless Control distance	1 m
Weight of Sliding Box	2 Kg

X Y direction displacement	0.25 m in the X 0.25 m in the Y
Durability	10 years
Reliability	90% success rate.

We didn't have any difficulties with the cost of our project. We will be using materials that are easy to use and valuable for graduate level classes. Our client is looking for a design that is easy to use. Most of the targets were given to the team from the client. The design of our device limits the displacements in both directions to the values you see in Table 1.2.

2.3 Testing Procedures

To test the engineering requirements before proceeding, for the further design analysis. if the engineering targeting values are wrong or are not achieving or crossing the limit then we must change these values before moving on. Therefore, different sorts of testing procedures will apply for different requirements. These testing procedures are mentioned below. The most important part of testing is generating accurate graphs where we will measure the displacement using a regular ruler and compare it to the values that we got from the Arduino to generate the graphs needed. In this section we will go over the most important testing procedures for the design.

2.3.1 Spring Expansions

Testing spring expansion can be done by hand by simply expanding and compressing the spring and placing a scale by the side of it. If the compression is long or expansion is long then we need to change the targeted values. The spring is expected to deform at some point during the lifetime of the device and will have to be replaced by the client if needed. The team will use adjustable "removable" springs that will make the process of changing the spring position easy they also will meet the engineering requirement as they need a distance to move freely with the spring and can change its position at any time.

2.3.2 Elasticity

The main idea of this project lies the testing procedures. Because we want the students who are using the design to be able to understand how the elasticity of the materials will behave the elasticity should be included in our testing procedures. The process of pulling or pushing meet the engineering requirements and explained what elasticity means. The Elasticity of the material can also be determined in the same way by making a device holder of same material that can hold and stretch through two hands or, a machine available for stretching and determine its elasticity. Elasticity of any standard material is available online as well can be verified.

2.3.3 Pushing and Pulling Force

Pushing and pulling force can be determined through a force detection sensor. This sensor can determine a force applied by a human. a person who will push and pull the box in this project will exert force to this machine and will determine whether the force mentioned is correct or needs to be changed. We are going to use a force gauge to test the system. We will figure out how force is required to be added in there to not let the system failed. We have two kinds of forces in this design. First, it's the human force (push or pull) that will be exerted on the system. The other force will be gain from Hooke's law in equation 3

$$F = -KX \qquad (3)$$

that is what we get for the second force when the spring pulls the box towards the wall. We have negative sign multiply by the spring constant.

2.3.4 Surface factor

Surface factor can be determined by the friction factor and friction of any material used. We used carpet in the surface of our design so we could get the result that were expecting. The friction value can be collected online. Applying the formula to calculate the frictional force will help us in getting the exact results. The surface factor meets our engineering requirements, such as adding carpet will make it easy to use, since we have push and pull surface. When the student pulls the design with the springs on the other side, the force will help us to pull on the reverse side. In this case, we will have a higher surface factor force.

2.3.5 Weight of a system

The overall weight of a system is what we added to our design to make it easy to hold. We added light wood to the surface of the design, which made our design lighter weight and more accurate. The result that will be collected is from the user because he will be able to hold it. The weight of a surface meets the engineering requirement by getting the wood and adding it to the surface. That made a huge difference in our design. We estimate that our design will be around 18 kg. To test that we used a scale to measure the total weight of the device.

2.3.6 Length of Sliding Area

The sliding area length is standard size, and it can check through any slider that is satisfied. Increasing the sliding area could result in increasing the total weight of the system, for which we are limited to around 40lbs. We used light material so the frictional force can move easily over the system. The dimensions of the whole device are easy to collect, and the materials that are used meet our client satisfaction and engineering requirements. In case of safety and sliding friction force. This will be measured by a ruler, so there will be enough area for the box to maneuver.

2.3.7 Sensors

The first step will be testing the sensor by connecting it to a computer and checking if it's reading data or not. Then we'll be testing the accuracy of the sensor by using professional equipment, like a force gage. As for the displacement, we will be using a ruler and comparing the measured value with the program output.

2.3.8 X Y Direction Displacement

This is the displacement measure, and it just needs to be checked by moving the box over the scale that it is giving the correct value or not. The box will only be moving along the x and y-axes, where we will be also testing how freely it's moving. The box should not be affected by any resistance that is not either the frictional surface or the springs. Basically, Fu is the output force that we will get when we move along x-direction. However, the Fv is the output force that we will get when we move along y-direction.

2.3.9 Arduino-UNO

When connecting all the sensors together through the Arduino board the Arduino program will test it if it's compatible and the setup is correct, so it will give us data. However, if we test the design and isn't compatible, then there will be something wrong with our set up connection, and we need to figure that out. Codes will play a big role with testing whether this sensor is working or not.

2.3.10 Reliability

Our team decided to use reliability items in our design. We used lightweight materials such as aluminum and springs. Our result will be collected through the Arduino connected from our design to the laptop. The higher the accuracy of the readings, the more reliable the device is. Then the user will find the results showed by a graph and by measuring the actual displacement with a ruler and comparing it to the readings on the computer screen. The customer requirements meet the engineering requirements such as safety.

2.4 House of Quality

Quality, refers to meeting the needs of our client. The House of Quality (HoQ) basically shows the correlation between the customer and engineering requirements. The customer requirements come directly from Dr. Feigenbaum, as she insisted on making the system easy to carry and store in an office. We came up with the engineering requirements that helped meet the customer needs, where we specified the size and weight of the system. The below caption will give a brief description of the first few customer requirements with the engineering requirements related to it and the completed HoQ will be on the Appendix A.

Customer Requirement	Weight	Engineering Requirement	Compat Design	Weight of system	Frictional Factor	Motion/Force sensor
1. Easy to be stored in an office	10		9	3		
2. Visable from a distance	4		1			
3. Desktop sized	8		9	3		
4. Various types of spring	1					
5. Portable	9		3	9		
6. Easy to carry	6		3	9		
7. Generate different types of graphs	7					9

Figure 1: Caption taken from the HoQ in appendix A

3. EXISTING DESIGNS

This chapter will explain different terms about the design. First thing is to find different existing designs. Existing designs help in making the design project, because some ideas can take from the existing designs. Knowing that for any design project there are two levels one is system level which is the overall product and second is sub-system level of product. Sub-system level of the product are those major parts which have their own existence. These sub-system parts play important role in the product and designing of these parts is critical part of any design project.

These sub-system levels also need to explore and these can explore through finding their existing designs which will help them in actually implementing these parts. And in this section, we did research on design process and found existing designs for system level product and also found existing designs for the sub-system level parts of the product.

3.1 DESIGN RESEARCH

Understanding the plastic deformation of metals is exceedingly significant to all parts of atomic metal segment execution, from creation through to decommissioning. Plastic deformation of metals is an exploration region which presents numerous difficulties, for example, the compromise of the discrete age, development and reworking of separations and different imperfections at the nuclear scale, right off the bat with examples of deformation at the microstructural scale and eventually with the easily fluctuating continuum mechanics which supports the building models at the part scale.

In spite of the fact that diffraction crest profile investigation has for quite some time been utilized to evaluate parameters, for example, separation thickness and grain measure, these strategies have regularly demonstrated an absence of concurrence with transmission microscopy thinks about. This has prompted an absence of enthusiasm for improvement, regardless of the immense potential in the territory. The Materials Performance Center is endeavoring to accommodate this current divergence, through a dynamic program of research in the territory of the plastic deformation of metal: as of now the MPC has around ten PhD ventures which either concentrate altogether upon or depend intensely upon a comprehension of plastic deformation. These incorporate various tasks utilizing novel ways to deal with the investigation of the impact of it work on pressure consumption breaking (SCC), and in addition inquire about into the plastic deformation of metals with a view to increasing further, vital comprehension on the most proficient method to create atomic parts. An as of late finished EPSRC-financed venture took a gander at how diffraction procedures could be utilized to portray the disfigured express: this task used precious stone plasticity displaying to comprehend existing suppositions and proposing valuable rules for deciphering the aftereffects of these distinctive strategies. The discoveries of this undertaking will add to the improvement of future precious stone plasticity models and will likewise give a structure that will be valuable for mass characterization of illumination harm in metals. A choice of current tasks is featured in additionally detail underneath.

In spite of the intrinsic many-sided quality, or maybe as a result of it, the plastic deformation of metals is an interesting field of study. It is seriously remunerating from a logical perspective and basic to understanding the execution of auxiliary segments in an atomic power plant at all phases of life. The MPC trusts that drawing in with such difficult parts of atomic materials inquire about is crucial to maintaining an energetic and consistently advancing exploration culture.

3.2 System Level

In the current project, the major objective is to focus on plasticity modeling by looking at its significance. Linear elasticity model is very crucial, specifically to modeling materials which undergo small deformations, and which return to their original configuration when the load is removed. This illustration is shown by use of springs on a block placed on a table. When the spring is pulled by the user, it stretches until its elastic limit is reached. When there is a lot of friction, the spring stretches more, as opposed to when the friction is less. In this regard, during the real applications of plasticity, an allowance should be given in extreme cases of friction i.e. a lot of friction or very little friction. This means that during building and construction and manufacturing of various products, their tensile strength should be considered so as to avoid accidents.

The current model has a wide range of applications as discussed below. In the building and construction industry, concrete is a very crucial component and is a mixture of sand, ballast, and cement. The right mixing ensures that the concrete is able to withstand heavy loads. On the other hand, gaps are normally left in between large portions of concrete so as to avoid cracking of concrete when the temperatures are high, or when it is subjected to extremely heavy load. Another application of plasticity is in the spring balance, which is used to measure weights. When a load is attached to a spring balance, the spring stretches up to a certain limit so that the correct weight can be read from the calibrations. If a very heavy load is hung on the spring balance the spring will stretch until its elastic limit is reached. The spring results in an irreversible deformation.

3.2.1 Existing Design #1: Elastic

This entails an ideally elastic plastic model, whereby a spring is fixed on a block and then pulled along a surface. The spring stretches as the block resists moving. Once the spring is full stretched, the movement becomes constant. This model is significant and it is one of the most successful plasticity models. This model requires a single experimental input. The yield strength. Flows under various boundary conditions are analyzed. It is mostly used in the analysis of the processes involved in the formation of metals and the carrying of loads. In addition, the model can also be used in the description of the yield stress fluids, like greases and toothpastes. However, this model can mostly be applied in light objects, which do not require a lot of strength to make them move [1].

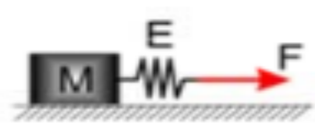


Figure 2: Figure that shows the yield strength [1]

3.2.2 Existing Design #2: Linear

This design entails rigid linear hardening whereby a spring is attached to a fixed point and one end is attached to the block. In this case, when the force is applied to move the block, movement is constant as the spring stretches uniformly. In this case, when the stress is below the first yield strength, the material is inflexible, and this makes the stress to increase along a vertical line, $\gamma=0$. In this case, elastic deformation is neglected. When the stress is increased again, and often goes beyond the initial yield strength, then the material starts to move. When the stress-strain curve monotonically increases, then the material is regarded to have strain-hardened. The idea behind this model is to reduce friction on the surface on which the block is moving, so as to facilitate movement. Also, a limited amount of force is applied by the user [2].

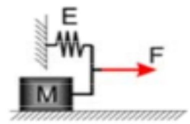


Figure 3: Shows the strength [2]

3.2.3 EXISTING DESIGN #3: SPRINGS

This design entails elastic linear work hardening, which entails use of two springs, whereby one is attached to the block while the other one is fixed. On pulling, the result is that the stretching is constant until the elastic limit is reached.

When two springs are used the strain is distributed equally between the two springs Hence, the springs do not undergo complete deformations. Also, there is a lot of strength as a result of the two springs. However, this strengthening occurs as a result of dislocation movements and dislocation generation within the two springs. This method is normally applicable in materials which have a high rate of hardening. In this regard, the two springs do not undergo maximum deformation since before the elastic limit is reached movement would have occurred. Therefore, this method can perfectly fit movement of relatively heavy blocks [2].

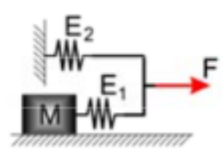


Figure 4: Design elastic work [2]

3.3 FUNCTIONAL DECOMPOSITION

Below we breakdown the main parts for our project and we came up with the following Block Box that should be weightless and attached with 2 springs. We are going to use 2 springs; one will be connected between the rigid wall and the box that cause deformation, however, the other spring will be used to pull or push on the spring. The main work will be on the X and Y axis as the client doesn't want us to use the Z axis. Lastly, we are going to use 2 kinds of sensors: one to measure the distance between the block and the rigid wall, other to measure the speed for the user.

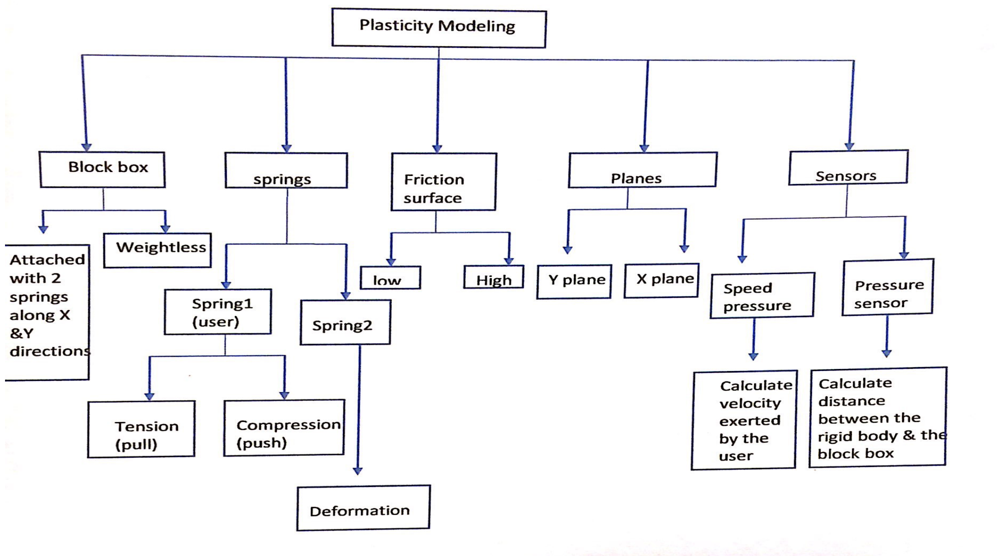


Figure 5: Functional decomposition for our design.

3.3.1 Black Box Model

The Black Box Model simplifies the functionality of the system and also lays out its inputs and outputs. For our case, the main function is to generate graphs of forces acting on the system, where we input a force which caused displacement, which eventually plots a graph as an output. Below in Figure 6, is the Black Box Model.

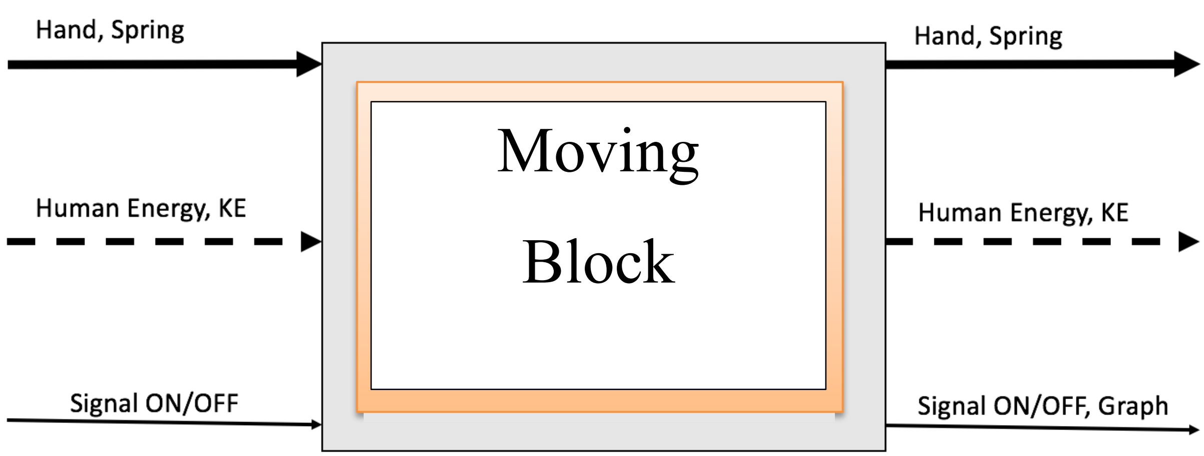


Figure 6: Black Box Model

3.3.2 FUNCTIONAL MODEL

This functional model is burned down in a way that clearly shows how the design works and, in each step, it shows what energy is used. This will definitely give a team a clear idea of how the system should work. As we start with sliding the box and give the spring tension or compression, we are exerting a mechanical energy. When the friction happens that will lead to a thermal energy; the sensor will translate all the codes into Arduino, and then it will plot the graph, and that will be the electrical engineering.

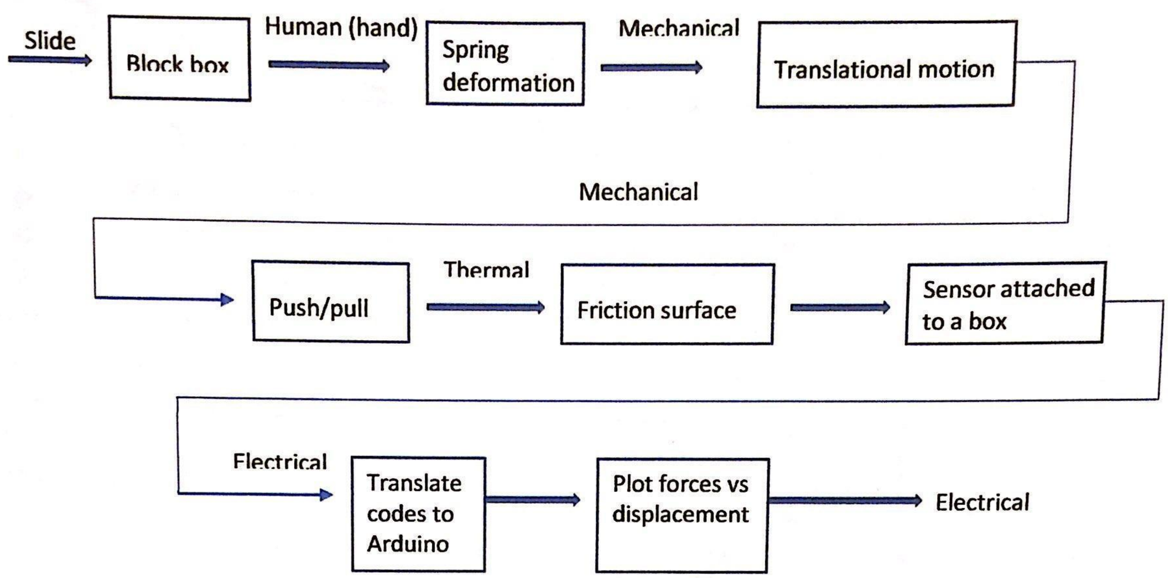


Figure 7: Functional Model

3.4 SUBSYSTEM LEVEL

The subsystem level is important in our project. Without those components we couldn't build our design. Around system level ten? We are going to create the plasticity design. Our client gave us couple of things that she is looking for on the final design such as Arduino, microcontroller, and springs. Output data is the data that will be used to create the device that our client wants. For example, the row data input coding is the data that inputs the codes we will be doing on the MATLAB. Applying Arduino codes set up the connection between the device and the codes we set up the final input. Also, microcontroller will be used to activate the codes of the device. The force system will be calculated after we get the final test.

The table top display shows the final numbers and forces that we calculated on the design. The system will include suction cups below the surface to keep it from moving/falling when force is applied. displaying outputs of the final shape of the device that we will be creating. Force gauge is the force that we will be used to move the design from one side to the other without any damages. Spring deformation gauges are the springs that will be used to activate the device and making the force move and help to define the spring constant.

3.4.1 SUBSYSTEM #1: ARDUINO CODES SET UP

In this design, we are going to use the Arduino connected with the 2 sensors to translate all the codes we are running to plot the F_x vs u, and F_y vs v. so we need to go over all the kinematic equations and figure out how to set them up using the Arduino program. Then we need to explain the connection between the sensors and the Arduino and apply it to excel for the plot.

3.4.1.1 EXISTING DESIGN #1: ARDUINO PROGRAMMING

if the user pulls or pushes the spring weather is in the X or Y axis it should do all the calculations and at the end of the process should plot a graph of the force versus displacement. The time will be calculated using a stopwatch and then will be apply it over the displacement to get the velocity and acceleration. At the end we will be able to get the force. By using this device, it will help us to get the graph we need right away.

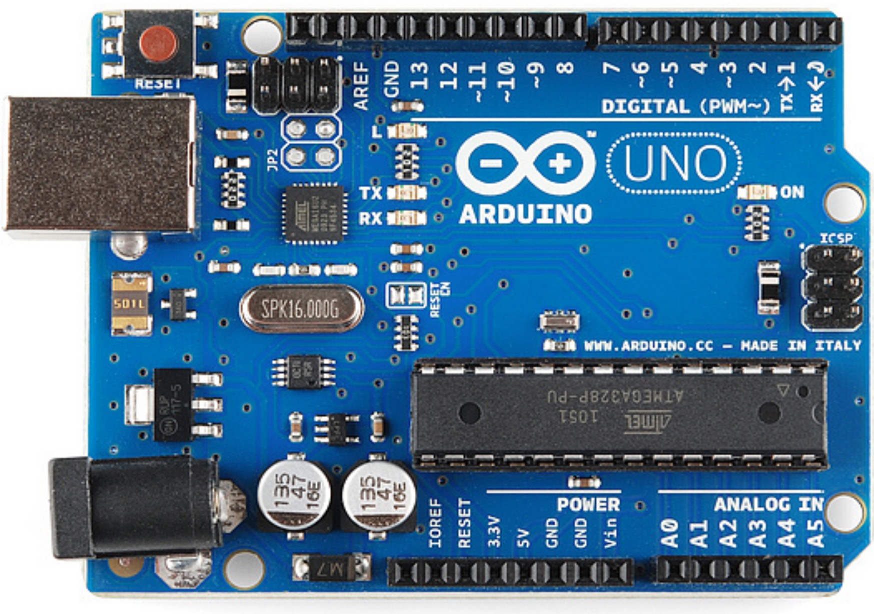


Figure 8: Arduino Uno [3]

This device will play a big role in our design since it's considered the main electrical part and all the connection will be through the Arduino board. We will be connecting all the wires with the sensors and the Arduino Then we will program it through the Arduino program using some IF commands to have the codes for force VS displacement. Then we should have our results for the graphs and the force gauge also will be connected with the Arduino to give us an accurate reading for forces applied by the user to the system design. This part is very important in term of meeting the engineering requirements, as students want to see a nice curve for Forces (u,v) vs.

displacement. in the end, we need to program all the codes we have from the Arduino and connect it to the Excel to display the graphs.

3.4.1.2 Existing Design #2: Sensors

For our design we are going to use 2 kinds of sensors. We will program one (BMP180) sensor, which is the pressure sensor to calculate the distance between the block and the rigid wall as the time is calculated using a stopwatch. Furthermore, the other sensor will be used to calculate the speed for the user. This kind of sensor (LM393) can give us a perfect approximate for the user speed.

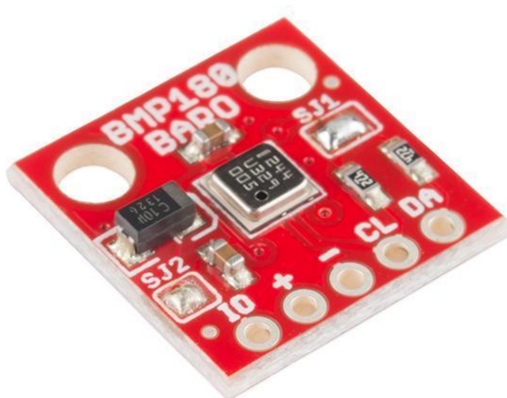


Figure 9: The figure show the speed sensor we will be used[4]

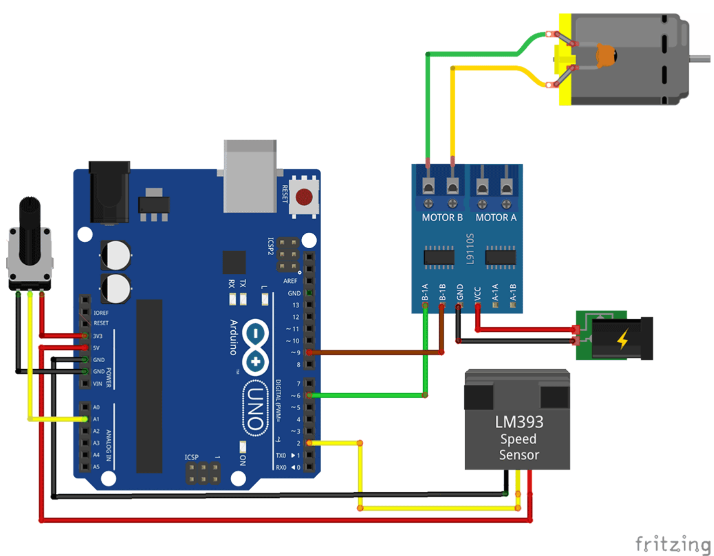


Figure 10: Shows the connection between the LM393 & Arduino [5]

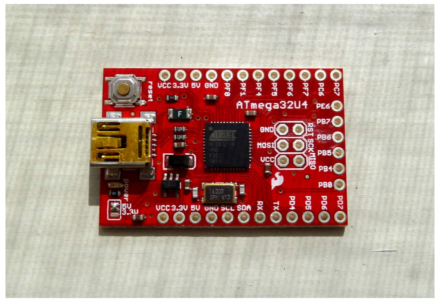


Figure 12: The figure shows the bored of the microcontroller that will be used. [6]

We used two kinds of sensors. Speed sensors and pressure sensors. The speed sensor is BMP180 which helped us in calculating the surface speed. Pressure sensors helped us in calculating the distance from the point of pushing to the point of pulling. Adding force gage will help us to have an accurate reading of the force that has been applied to the system. Our sensor meets our engineering requirements in the case of adding it to the Arduino. The pressure sensor will go right after the box and will be attached in the spring as well. However, the speed sensor will be attached between the output springs and the box to measure the user speed when moving the box and then apply it all to the kinematic equation to figure out the acceleration needed to calculate the distance. The pressure sensor will be there to enhance our results.

3.4.1.3 EXISTING DESIGN #3: KINEMATIC EQUATIONS

Below are the equations to be applied using the Arduino program. As long as we calculate the acceleration, we can find the force. By using the kinematic equations with the speed sensor, we can figure out the displacement.

We define the force as

$$F = m * a$$

Velocity equation

$$V = \frac{\Delta m}{t}$$

Acceleration equation

$$a = \frac{\Delta v}{t}$$

Here are the kinematic equations to solve for the displacement:

$$d = v_i * t + \frac{1}{2} * a * (t)^2 \qquad (4)$$

$$(v_f)^2 = (v_i)^2 + 2 * a * d \qquad (5)$$

$$v_f = v_i + a * (t) \qquad (6)$$

3.4.2 Subsystem # 2: Springs

Spring is another subsystem of our project which is quite important for the compression and expansion of object. There are some existing designs already available.

3.4.2.1 Existing Design # 1: Constant force Springs

Such springs are uses to apply constant force and they don't get expanded and compressed in the given situation when the constant force is applying to them but these springs expand or compressed when any external force apply to them along with the constant force. When external force applies to them these springs compresses or expands according to the given situation.

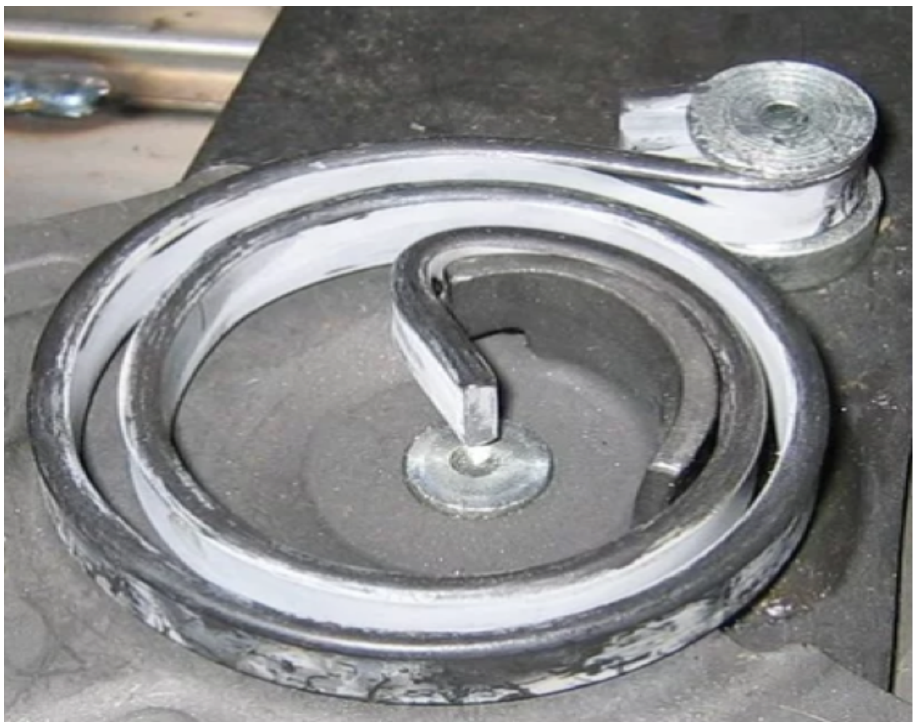


Figure 13: Constant force spring with the constant force apply on it. [7]

3.4.2.2 Existing Design # 2: Torsion Spring

This is another existing design of spring available to use. The torsion spring rotates around the axis to create the load. When any external force applies on it, it provides the space to rotate the item because of its compression and then force releases it gets back to its original position.

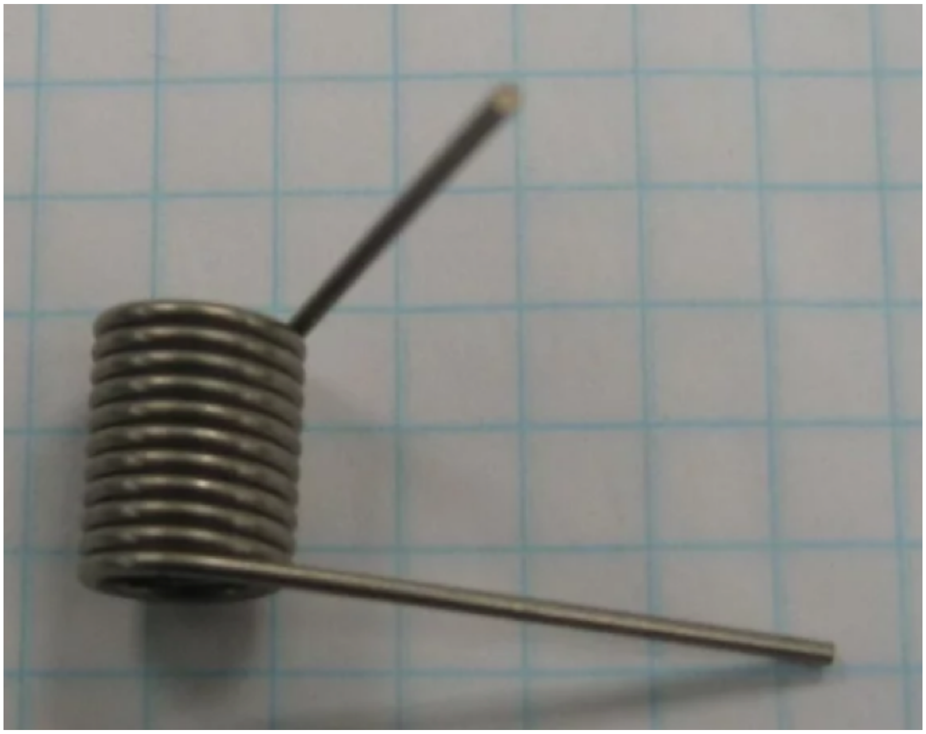


Figure 14: Torsion Spring [7]

3.4.2.3 Existing Design # 3: Extension Spring

This type of spring provides the parts to stretch and create load as they have loops at the ends to attach with different parts. As they are soft and stretchable they usually use for the bends and providing soft load on any object.

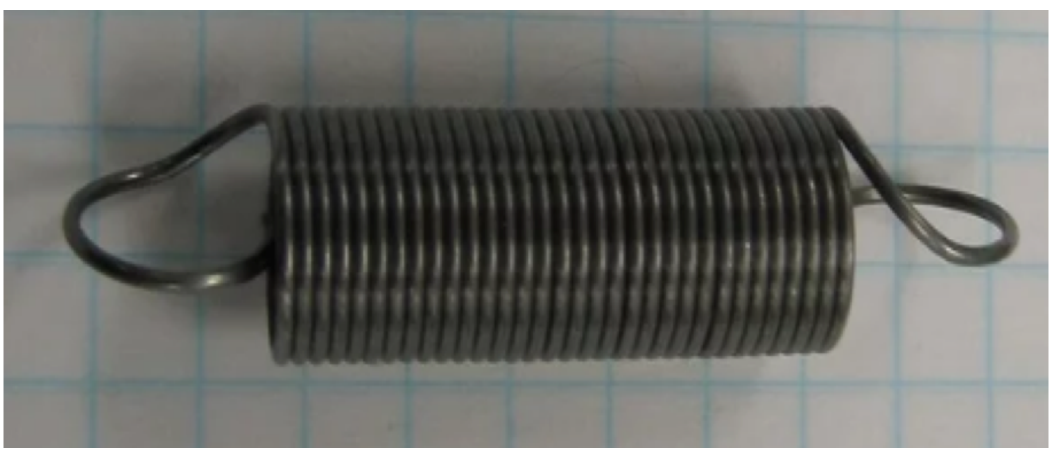


Figure 14: Extension Spring [7]

3.4.3 Subsystem # 3: Box

Box is another sub-system of our project; all the electronic components will save in it therefore this is quite important as well. There are some existing designs for this subsystem present as well.

3.4.3.1 Existing Design # 1: Wooden Box

Wooden box is strong and secure as well for putting the electronic components. Wooden being an insulator to electricity will not allow any current to leak and will save the all the equipment's present in it because of its strength.

Figure 15: Wooden Box [8]

3.4.3.2 Existing Design # 2: Plastic Box

Plastic box provides the insulation to all the components store in it and also it is light in weight as well but it is not as strong as the wood is. Components can view from outside of this box and see if any connection is right or wrong. This box can also use in our project.

Figure 16: Plastic box [9]

3.4.3.3 Existing Design # 3: Aluminum box

An aluminum box is also useful in our project as it is lightweight and it is strong as well and it will provide the safety to the items present in it but it can leak the current because of its conductivity to the electricity.

Figure 17: Aluminum Box [10]

4. DESIGNS CONSIDERED

In this chapter of the report, we will discuss the designs that the client suggested and also designs that the team considered. There will be a list of advantages and disadvantages of each design that will help us narrow down the options and eventually choose our final design to go forward with. Below you will find figures and diagrams that will help you visualize the system as a whole.

4.1 Design # 1: Simple Basic Module

This is the first design idea in which we have placed two springs: one is fixed from both sides and the second spring is open from one end. In this way the box will move with the help of the springs by stretching the spring. The displacement covered by the box will be recorded in the system through the help of Arduino controllers. The controller and system will generate the graph of force vs. displacement. Here is the module showing this below in the figure 13.

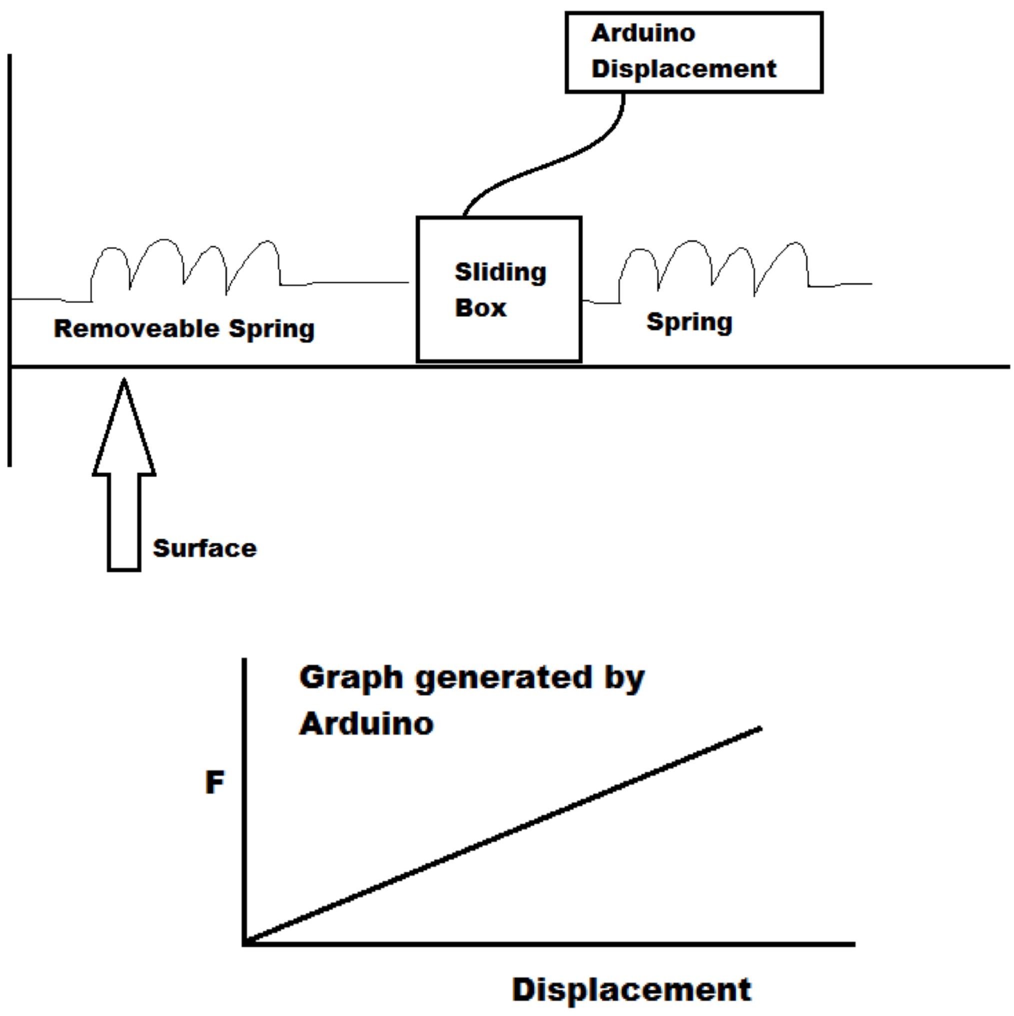


Figure 13: Basic Module

Advantages

Following are the advantages

1. The removable spring can make it easy to adjust and slide over the surface.
2. Spring elasticity will not affect material elasticity.

Disadvantages

Following are the disadvantages

1. For drawing the force vs. displacement curve we need an extra computer screen to draw and show the curve.
2. Processing will be slow because of the extra screen attached to it.
3. It will be difficult to make it portable

4.2 DESIGN # 2: FORCE GAUGE SCREEN WITH SIMPLE MODULE

This is a design amended from the previous design and in this design, we will put a force gauge in the system, so that force will be determined through the screen continually. The remaining removable springs have been attached as well which can be removed at any instance. This design is shown below in the figure 14.

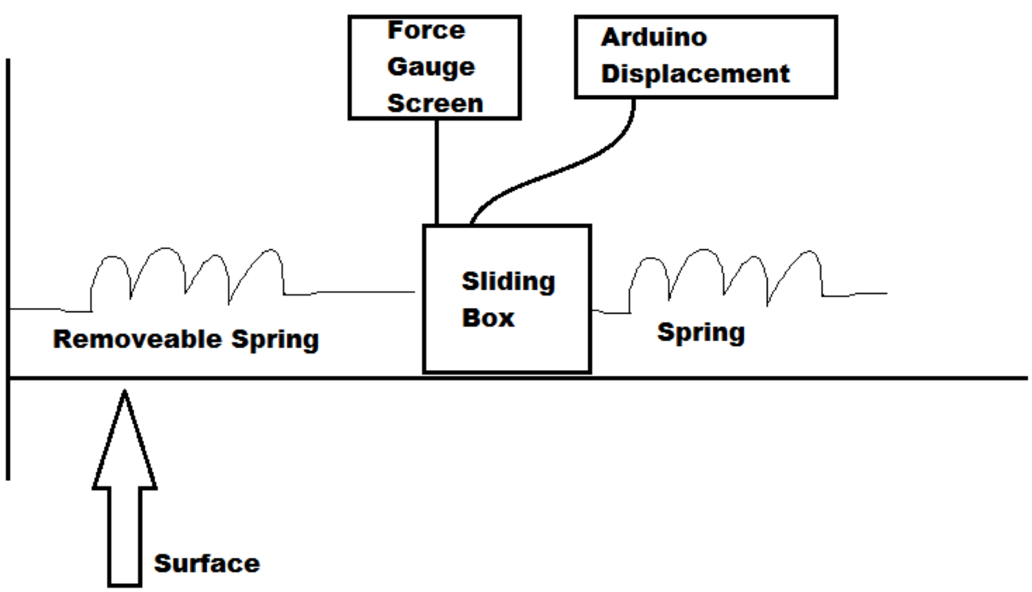


Figure 14: Simple Module with Force Gauge

Advantages

Following are the advantages for this design system

1. The Force curve is available so force will be monitored continually and it can vary eventually.

2. The Removable spring can make it easy to adjust and slide over the surface.

3. The Spring elasticity will not affect the elasticity of the material.

Disadvantages

Following are the disadvantages

1. The Force vs. displacement curve will be formed by the system which makes the system slower.

2. Will not be portable.

4.3 DESIGN # 3: FORCE AND SPRING GAUGE WITH SIMPLE MODULE

This is another design in which two gauges have been added in the system. One is the force gauge and second is spring gauge. In this way the whole system will able to draw the curves of force and displacement at the same time and can monitor both curves live and make the system portable and easy to carry. Following is the figure showing the design idea.

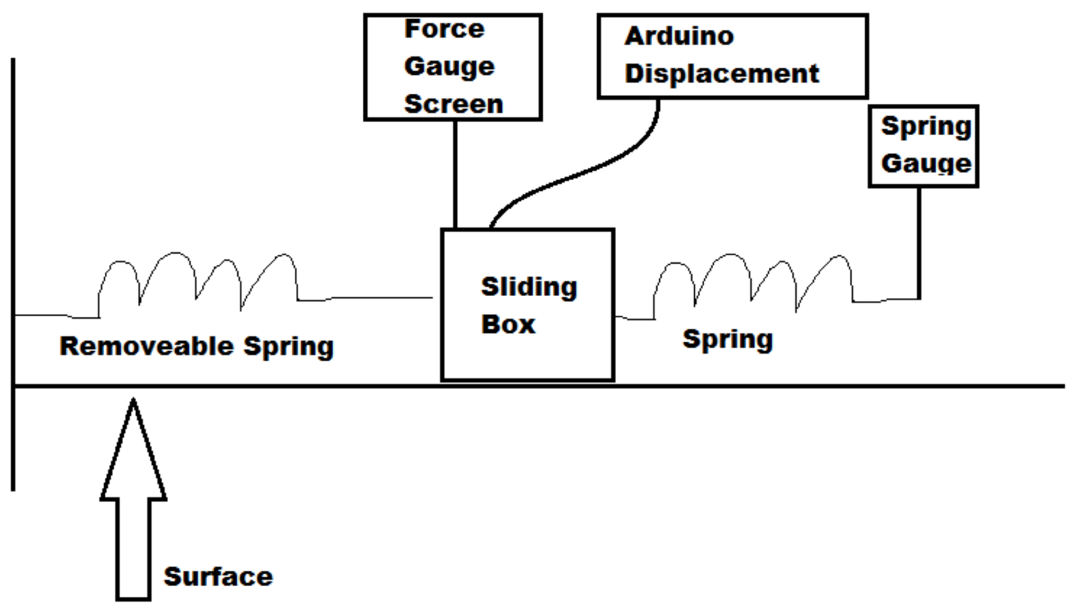


Figure 15: module springs

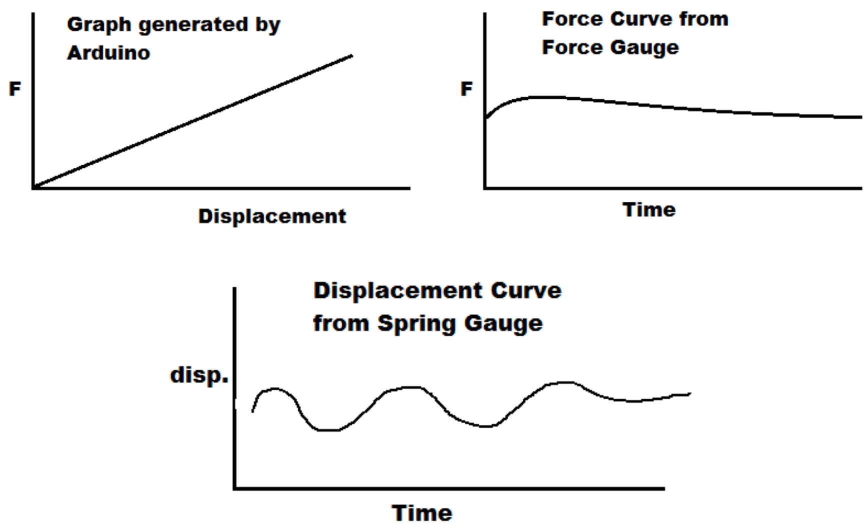


Figure 15: Simple module with force and spring gauge

Advantages

Following are the advantages of this system

1. The displacement and force curves will be monitored through the gauges.
2. It is easy to understand the material behavior from the live gauge results.
3. The removable spring can make it easy to adjust and slide over the surface.
4. Spring elasticity will not affect the elasticity of the material.
5. Portable system

Disadvantages

Following are the disadvantages of system

1. The Interlink of force gauge and spring gauge to form the force vs. displacement is difficult.

4.4 Design # 4: Box sliding over frictional surface

This is another design that we found about frictional force and how it is affecting the system, shown in figure 16 below. Here we will consider the frictional force acting against the applied force by the user, forming a type of resistance. The surface of the system will have a friction coefficient, which will be determined later on, where we will consider the safety of the user when it comes to the roughness of the surface.

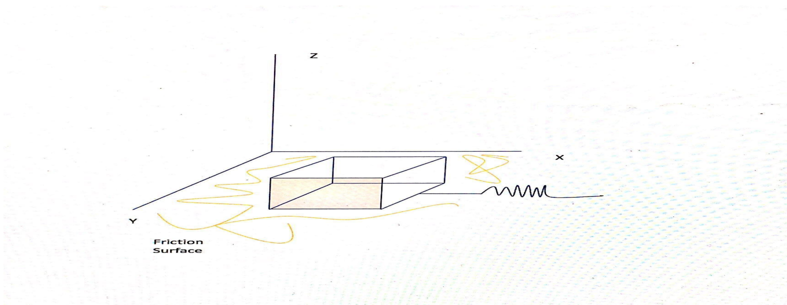


Figure 16: Box sliding over frictional surface.

Advantages

1. Additional resistance.
2. Visualizing how friction acts on the given material.
3. Has a more interesting Net Force acting on the box.

Disadvantages

1. The frictional surface can be dangerous to the user.
2. The user must be careful of his hand.

4.5 Design # 5: Box attached with a spring all connected to a rigid wall

This is design shows how the springs are important to the overall design, as shown in figure 17. Having springs is one of our client's needs, where she specified being able to add/remove springs on demand. Adding another feature to the design, which is being module. It shows how we used walls to act as a resistance force, which also makes things more interesting when studying the elasticity of a certain material.

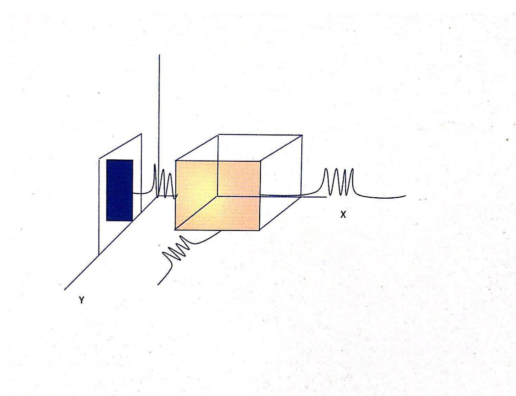


Figure 17: A box with spring connecting to the rigid wall

Advantages

1. Springs are applied in both the x & y directions.
2. Module Built.
3. Adds resistance to the force applied.

Disadvantages

1. Multiple users required to use the system.
2. User must be careful because of the springs.

4.6 Design # 6: Box connected with a spring & the rigid body is connected on the z plane

This design shows the force applied in the z-direction. As shown in figure 18 below, we added another wall that works in the z-direction. This type of force can cause deformation to the box, which satisfies the cause, but also is not required. We can see the box deform as it reaches the elastic state, but it will also need to be replaced after a trial.

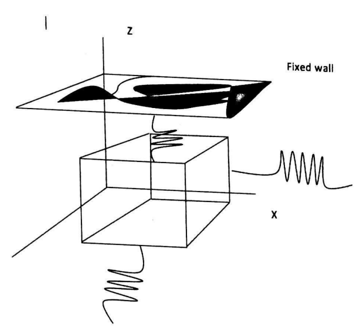


Figure 18: A box connected with springs along X & Z axis

Advantages

1. Applied force and displacement
2. Friction is applied

Disadvantages

1. Springs are on different sides.
2. 3D design - not required.
3. Different boxes.

5. Design Selected

In this section we will talk about the design that we are developing. This section includes the rationale design selection which focuses on the purpose of the project. The Pugh chart which shows the different types of requirements and what the client is looking for is also shown. the decision matrix is an important part of this section which has the weight and frictional link. This section will narrow down our options into our final design selected.

5.1 Rationale for Design Selection

The purpose of this project is to understand the elastic behavior of materials after they have reached their elastic limit. For this purpose, we are building a product which can read the behavior of a system by sliding the material box over the surface. The product will then develop a force vs. displacement curve which will help us in understanding the material characteristics. Therefore, a few design ideas have been presented in the previous section and in this section. we are finalizing the design idea and selecting the one when will actually be implemented. In order to finalize the design ideas, we have used two different techniques the first one is Pugh chart and the second one is decision matrix.

Pugh Chart

The Pugh Chart is a type of chart which determines if the engineering requirements and client requirements are met. Our design met with the engineering and client requirements. We came up with 10 different designs that will help us in creating our design. The Pugh chart helped us narrow down our options from 11 designs to the best design. The team gave each customer requirement a certain weight and also listed them from most important to the least. The design with four springs in all directions was set to be our datum. The reason behind that, is that we're expecting our client to use at most four springs. We then compared all the other designs to it and visualized how the other designs exceeded the datum or failed to meet our expectations. The design with the highest total is set to be our final design.

For this project we have selected the top two ideas from the Pugh chart and these two ideas are:

1. Force Gauge with Simple Module
2. Force and Spring Gauge with Simple Module

The above two designs have narrowed down from the Pugh chart because both designs have gauge screens which given benefit to plot force vs. displacement graph. Design number 3 has a portability advantage as well. that's why these two designs have narrowed down for the final result. Next step is to put these results in decision matrix to narrow down the result.

Table 1.2: Pugh Chart

10 Designs	Weightage	Simple Basic Module	Force Gauge Screen	Force and Spring Gauge	Sliding Box	One-wall attachment	To wall with three springs	Two-walls springs	Rollers Sliding Box	Pressure sensor	Spring in four directions
Desktop sized	8	+	+	+	-	+	+	-	+	+	Datum
Large to seen in classroom	7	+	+	+	+	+	-	+	+	-	Datum
Small to store in office	6	-	+	+	-	-	-	-	-	+	Datum
User control	5	+	+	+	-	+	+	-	+	-	Datum
Tension and Compression	4	+	+	+	+	+	+	+	+	+	Datum
Direction of force	3	-	+	+	-	-	-	-	-	-	Datum
Tabletop model	2	+	+	+	-	-	+	-	-	+	Datum
Module Built	1	+	-	+	+	-	-	+	-	+	Datum
Number of Plus		6	7	8	3	4	5	3	4	5	Datum
Number of Minus		2	1	0	5	4	-	5	4	3	Datum

Decision Matrix

In the decision matrix, a matrix has formed in which each requirement has been assigned a specific value and that value has then multiplied with the number obtained by the design on the basis of its condition according to the requirement and summing up all the numbers for a design to get the result of each idea. The selected design will be the one which got the highest value.

Table 1.3: Decision Matrix

Decision matrix	Desktop sized	Large to seen in class	Small to store in office	User Control	Tension and Compression	Direction of force	Table top Model	Module built	Total
Weightage	8	7	6	5	4	3	2	1	
Force and Spring Gauge	6x8=48	6x7=42	2x6=12	7x5=35	7x4=28	5x3=15	5x2=10	1x1=1	191
Force Gauge	4x8=32	5x7=35	3x6=18	1x5=5	2x4=8	4x3=12	2x2=4	2x1=2	87

From the decision matrix we have obtained the final design as

1. Force and Spring Gauge with Simple Module

This design has an advantage over the other design is in a way that it is using two gauges which makes more easy and portable system. It can plot the force vs. displacement curve easily because these two gauges and these advantages make this design idea as a final design.

5.2 DESIGN DESCRIPTION

From the decision matrix we have finalized a design Force and Spring Gauge system which is shown below. The springs will be handled by the user. The force gauge is attached to the spring end, in order to pull on it and apply force. The Arduino will be inside a frame box which will be attached on the top of the box. The frame will also include displacement sensors on all four corners of the frame. The springs will be module, where the user can attach them to the hooks that are located on both walls and also all faces of the box. The Arduino and force gauge are then connected to computer software, which will display the force vs. displacement graphs.

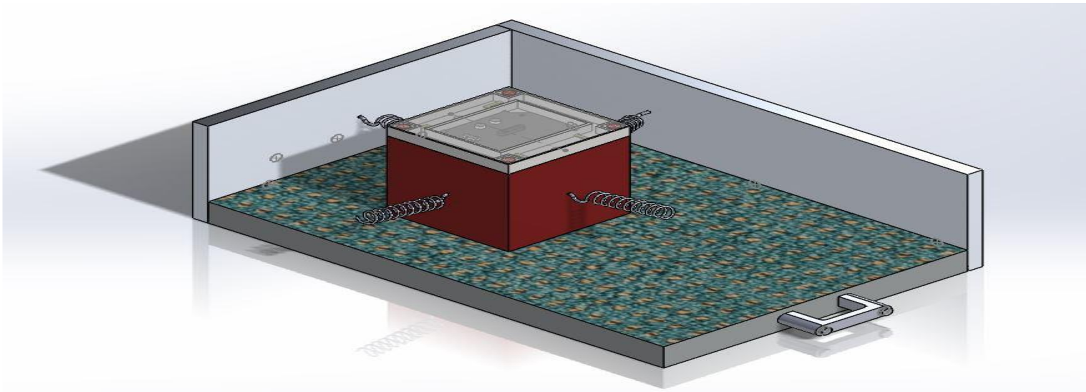
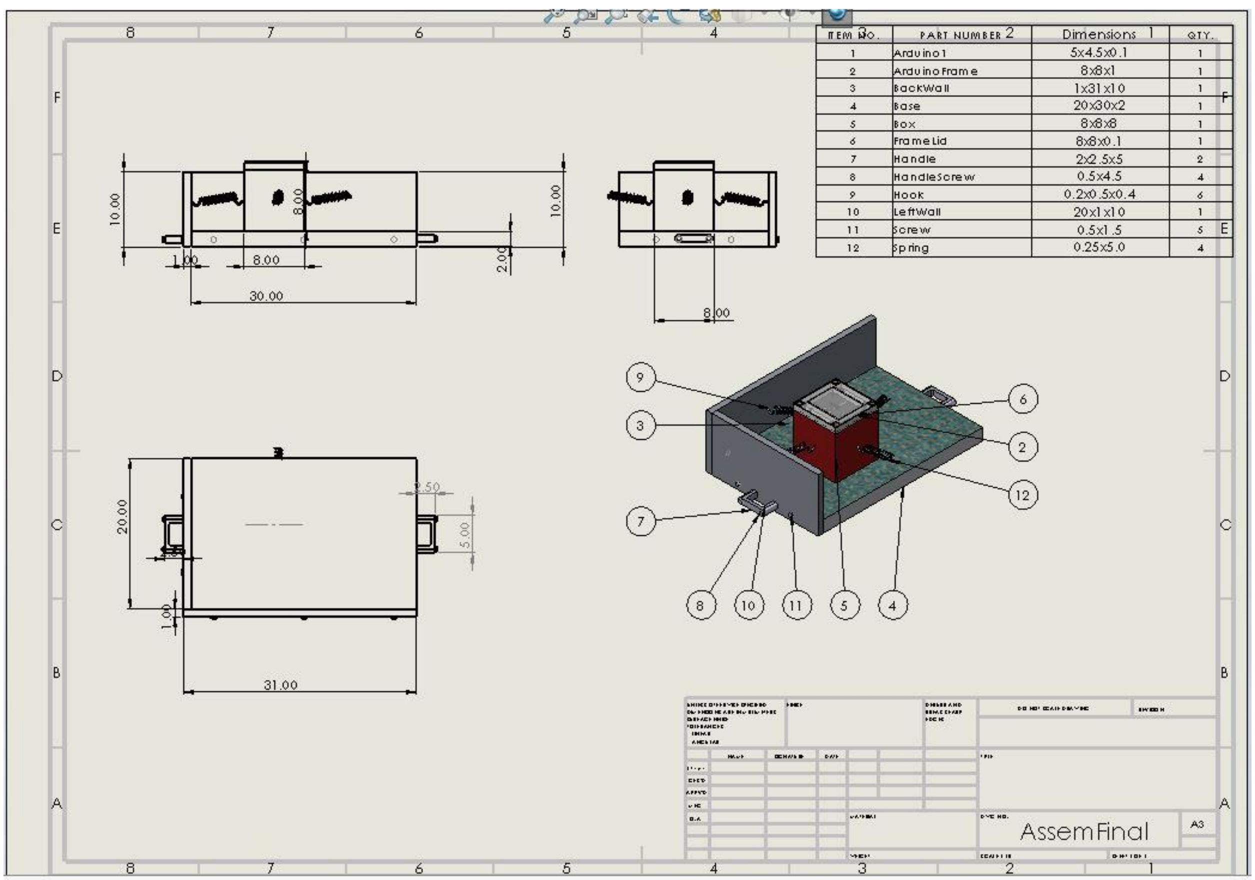


Figure 21: Final CAD Model

The walls and base will be made out of aluminum, which is considered a lightweight metal. It will help with the durability of the device, but also still be easy to carry and move around. The surface of the base will be covered in carpet, which will provide some sort of friction without damaging the box itself. The bottom face of the base will be rubber, which will help hold the device in place when in use. The box will be made out of polyethylene, a type of plastic, as specified by our client.



ITEM NO.	PART NUMBER	Dimensions	QTY.
1	Arduino1	5x4.5x0.1	1
2	ArduinoFrame	8x8x1	1
3	BackWall	1x31x10	1
4	Base	20x30x2	1
5	Box	8x8x8	1
6	FrameLid	8x8x0.1	1
7	Handle	2x2.5x5	2
8	HandleScrew	0.5x4.5	4
9	Hook	0.2x0.5x0.4	6
10	LeftWall	20x1x10	1
11	Screw	0.5x1.5	5
12	Spring	0.25x5.0	4

Figure 23: Final drawing with BoM

6. PROPOSED DESIGN

The design selected for this project has been presented already and we are ready to start the building process next semester. Further details of this design can be viewed from the bill of materials and schedule for the future work can be viewed from the Gantt chart. We will use the machine shop to build the frame and we will use hand tools in adding the springs and the carpet. The sources of our design will be bought online and the shipping and tax are including on the cost and budget chart. The Arduino frame will be molded to fit the Arduino and its sensors. The walls and base will have to be manufactured by the machine shop. This CAD model above include our finalized dimensions and materials used. The team is ready to move forward and start building the exoskeleton of the device, which is the walls and base.

6.1 BILL OF MATERIALS

The bill of materials (BOM) is helpful to simplify all the components of the system and its manufacturing process. It also specifies the quantities needed and the function of each part. The BOM may be upgraded in the future if the team came up with a slight change in the finalized design. The BOM is found in Appendix B.

6.2 GANTT CHART

The Gantt chart is present in Appendix C. The Gantt chart has the complete schedule of what's going to be in future. It shows all the tasks that the group will need to complete in order for the project to be a success. The Gantt chart is a good way to track the progress. From the Gantt chart we can also check if we are behind the schedule or not. So, in this way the Gantt chart helps in completing the project on time.

6.3 COST AND BUDGET

The budget will be team proposed to our client, where the range is between $500-$2000. Since the project total cost is lower than the range anticipated, the team is willing to start ordering the parts needed and hand the clients the receipts. The force gauges cost us almost 70% of our budget. The total cost of parts and shipping will be included in the BOM. As for the manufacturing price of the frame, it will be determined next semester when the team meets with the machine shop.

Following is the table of cost that has used to manufacture the product. These products have purchased, and all of the items have purchased from amazon. The products have included the shipping cost from amazon. And the total price we have spent is around $113. We have bought the starter kit which cost around $35. This kit is useful to run all the programming data and control the sensors. All the sensors attach to the springs will respond to the kit.

We have bought the tutorial for learning the Arduino and its programming. From the tutorial we have able to do the programming which will control the expansion and compression of spring. The box will move over the fabric sheet and fabric sheet provide an extra friction.

We have bought the sensor which measures the distance as the object will move. This sensor is module I2C interface with Arduino kit. Another sensor has used for determining the expansion of object, which is Sukragraha UNO R3 Sensor shield, V5.0 which connects with the Arduino Genuino System. Stainless steel ring hook, have bought with round screws. Expansion shield UNO R1 Nano 3.0 Duemilanove connect with Arduino has bought. Swordfish 31070 200 PC

Extended and Compressed Spring assortment case kit has bought which will use for connecting the expansion sensors.

Table 2.1: Cost Analysis

Item	Quantity	Cost
Elegoo EL Kit 003 UNO Starter Kit with Arduino	1	$34.99
Programming Arduino	1	$7.79
Swordfish for compressed and extended spring	1	$12.99
Hiletgo Nano Expansion Sensor Shield	1	$5.29
Stainless Steel Ring Screw Hook	10	$6.64
Ranging Sensor Distance Measurement	2	$13.99
Sensor Shield expansion board	1	$5.49
Box	1	24.92
Wires	1	$7.29
Total	$112.1	

7. IMPLEMENTATION

This section will include the steps we took into building the device. It will include the problems we faced and what we did to overcome it. The changes could be major or minor depending on the issue at that point. Any manufactured part will also be discussed in this section, from the materials used to the mounting part of the process.

7.1 MANUFACTURING

To build the frame, the team used wood as the base for the device and 8/20 Aluminum walls mounted to it. The handles were drilled in and screwed in place, where the hooks were attached to both sides of the wall. The walls were cut into the dimension wanted at the store for them to be screwed together to form the corner. The bottom surface of the device was covered with rubber in order to hold the device in place when in use. As for the box itself, we had it done in two pieces. The inside part acted as a compartment for all the electrical components, as the top part was finished with veneer and slides from the top to cover the housing. The screws on the box have two uses: to keep both parts of the box attached and to hang the strings to.

7.1.1 LASER SHOOTING TO CALCULATE DISTANCE

At first, we thought of using a laser beam that shoots to the walls and measured the distance displaced. The issue with that is that if the student only used one spring and moved in both the X and Y directions, the box will rotate in an angle that will cause inaccuracies in the data. Instead we decided to use an optical mouse to measure the distance. The first trial took thousands of data points every second, but gave an output of 0’s. We switched the mouse and the orientation in hopes of getting actual data. After running some tests, it shows that it’s giving values of 1’s but not actual movements.

7.1.2 EXPORT DATA TO EXCEL

There’s a high chance it’s an issue with the code, but there’s a slight chance it's the mouse itself that needs replacing. The team is determined to figure out this slight issue given the time frame in hand. Once the code part is done, then we can move on forward to using LabVIEW as a side program that will help export the data into an excel file. From there, it would be easy for students to generate graphs as a class assignment. Another program can be used to read data and graph them simultaneously.

7.1.3 CALIBRATE THE WEIGHT SENSORS

As for the weight sensors, they’re attached to the hooks and were calibrated using a known value. The team has tested other known weights to test the accuracy, where it showed to be highly accurate thanks to the amplifiers used to enhance the signal transferred from the weigh sensors. With that, it concludes all the manufacturing and testing done until now hoping the next testing will accomplish the task needed.

7.2 DESIGN CHANGES

The design has entirely changed in terms of the electrical components and the connections. The output collected is changed now as we need both coordinates to be measured at the same time. However, the overall design manufacturing stays the same. In this section we will be going through all the design changes, sensors connection, improvements, final design chosen, problems that were facing the team when dealing with the Arduino parts, and what we are planning to do from now until the testing proof date.

7.2.1 SENSORS CHANGED

The team has changed probably most of the sensors chosen in ME476C. What we found out now after we have been through the manufacturing is totally different from what we were expecting when choosing each sensor last semester. The overall design manufacturing in terms of the walls and the base shape stays the same, however we changed the BMP180, LM393, and the force gauge and replaced them with an Electronic Weight Sensor, HX711 Weighing Sensors 24bit, and ANDS-3050 optical mouse sensors. We did those changes on purpose, for example the most of the force gauges we found are expensive and it’s very hard to wire them directly to the Arduino.

Also, when the team met with the client last time, she was looking for the plots to have both forces and distance added up at the same graph. As the team was planning to graph each coordinate by itself, now we needed to generate a graph that gathers both forces and distance at the same time.

7.2.2 Electronic Weight Sensor Load Cell

Instead of using a force gauge to calculate the force exerted by the student, now we are using 2 weighting sensors: each coordinate has one. We drilled the outer hooks in the middle of the weight sensor and we placed it in a way that whenever the student pulls or pushes the box it will immediately read the force. They work by calculating each side of the wall and then take the average for both forces and have one accurate force.

7.2.3 ANDS-3050 Optical Mouse Sensors

Furthermore, instead of using BMP180 & LM393 together, the team decided to use a PS2 Optical mouse and those stands for “Personal System/2”. Also, it’s called gaming mouse, where people use them to play games with computer. They are known as an efficiency mouse for gaming as it is fast, and the chance of getting error with these are really low. What is interesting with these mice is that they took thousands of pictures while the mouse moves each second. The principle of these mice is that they’re made to work in both coordinates at the same time and they can be directly wired to the Arduino and this is what we are looking for in terms of the new data collected. The team was able to find some written codes online from other people that used it in other projects and that is the reason why we chose PS2 mouse, and that is why we found many sources that has a direct wire codes for PS2 to the Arduino.

7.2.3 HX711 Weighing Sensors 24BIT

HX711 is a weighing sensor that is like the second board where all the wires connect to gather and to give it more efficiency and accuracy for the reading force. There is also a linear actuator to help amplifier signals. All those components will take a part in our electrical connection and the figure 24 below will show all the connections that goes inside the box.

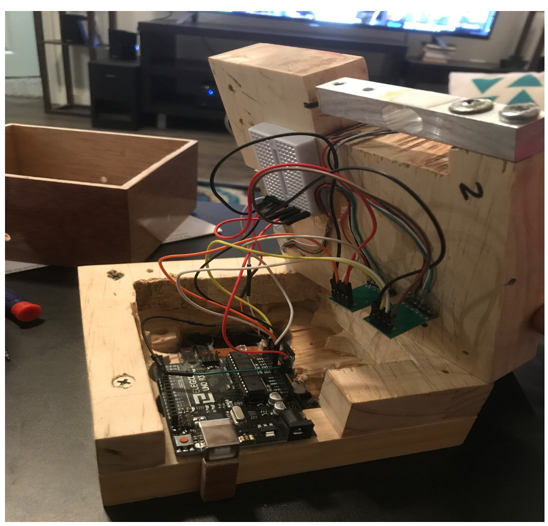


Figure 24: sensors connection inside the box

The potential resistors (Weighting sensors) will be mounted in the center on the box, where the sensor of the mouse will be located at the bottom of the box. It will take multiple images of the surface of the device and measure the displacement accurately. Both sensors will be connected to the Arduino board and programed to generate Force Vs. Displacement graphs. In figure 25, 26 respectively will show the weighting sensors and the PS/2 mouse.

Figure 25: Electronic Weighing Sensors

Figure 26: Optical PS2 mouse

7.2.4 IMPROVEMENT

We did improve with enhancing our design and improving it makes it meet both customer and Engineering requirements. The team has cut down the system size from rectangular to a square shape because we don't need that space and to try to make it light as possible as we can. We did add handle for both the Aluminum side to make the design easy to carry as that very major to the customer requirements, because we just need one person to be able to carry it with no other help. Rubber sheet added to the bottom of the base to prevent the system from moving when it's over the table top. Furthermore, group members have added hooks in each side of the box, while having some fixed at the aluminum. In this way, we will make it easier for the students to switch around the springs that will make it adjustable when the graph showing weird plot. The box that hold all the sensors connection was covered with a high-quality material, and that material is used with Jewelry. The edges are very sharp for the aluminum as well as the edges for the wood base, so we tried our best to cover those edges with wood filler, so it doesn't hurt anyone when holding the design and give it a great finish for the overall project. Below will see the figures from 27 to 32 with all the improvements happened with the system.

Figure 27: Handles added to the design to make it portable

Figure 28: Rubber sheet added to the bottom of the base

Figure 29: Cutting the size down to a square

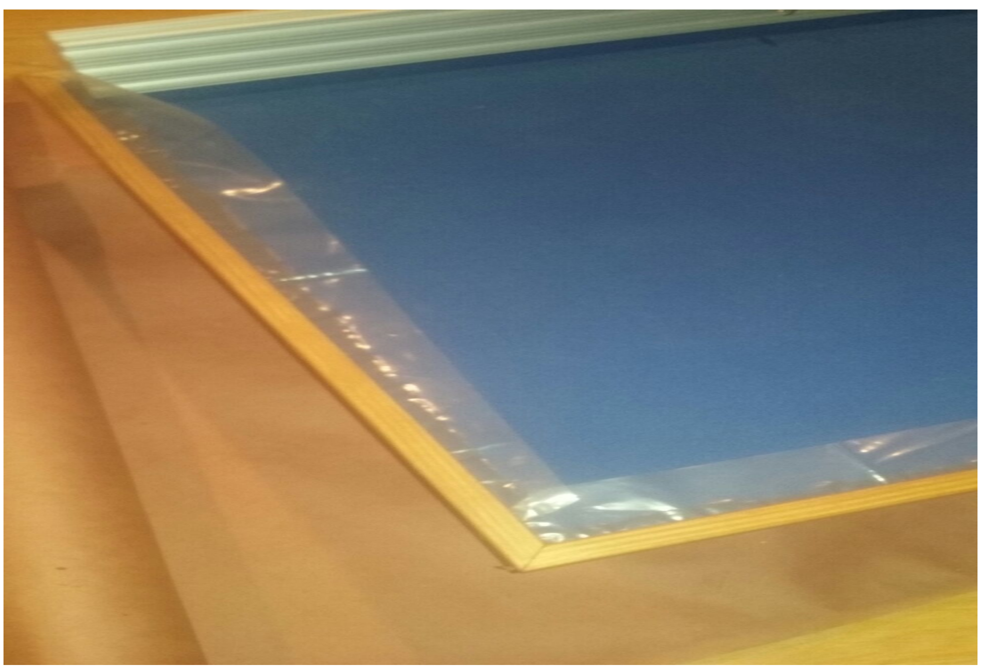


Figure 30: Cover the edges and sides for high quality finish

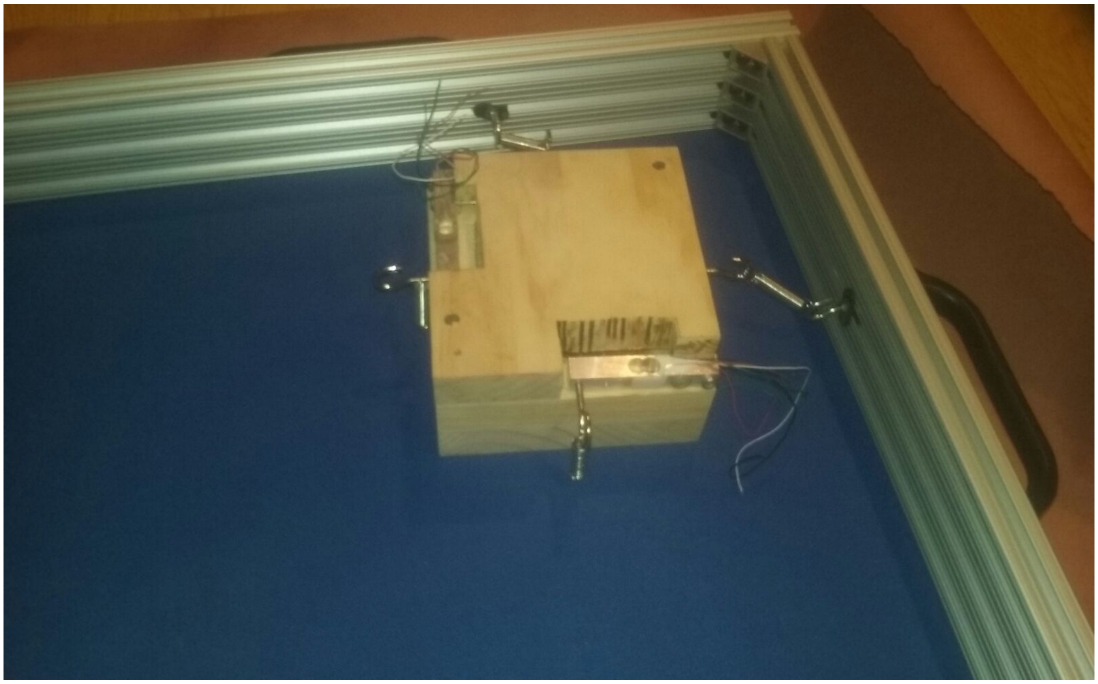


Figure 31: The initial setup for the box before cover it

Figure 32: The box cover with high quality material called "Veneer"

7.2.5 Final System

The team tried very hard to ensure that the final design has met all the customer and engineering requirements. We did add a fabrication sheet on the top of the base to give it a perfect sliding frictional surfaces. All the sensor connections go inside the box and we placed the Arduino in a position where it will be easy to plug the USB wire which will be connected directly to the laptop. The box was covered by a material called veneer to help get a better frictional surface as well as to give it a high-quality finish when looking at it. We have a box that gathers a multiple spring where it is changeable and adjustable for the student when using the design. Blocks were added to prevent errors when pushing the box. In figure 33 and 34 will show the top and side views for the final design respectively. After that will list some advantages and disadvantages for the final design.

Figure 33: Final system from the top shows all the springs and the blocks

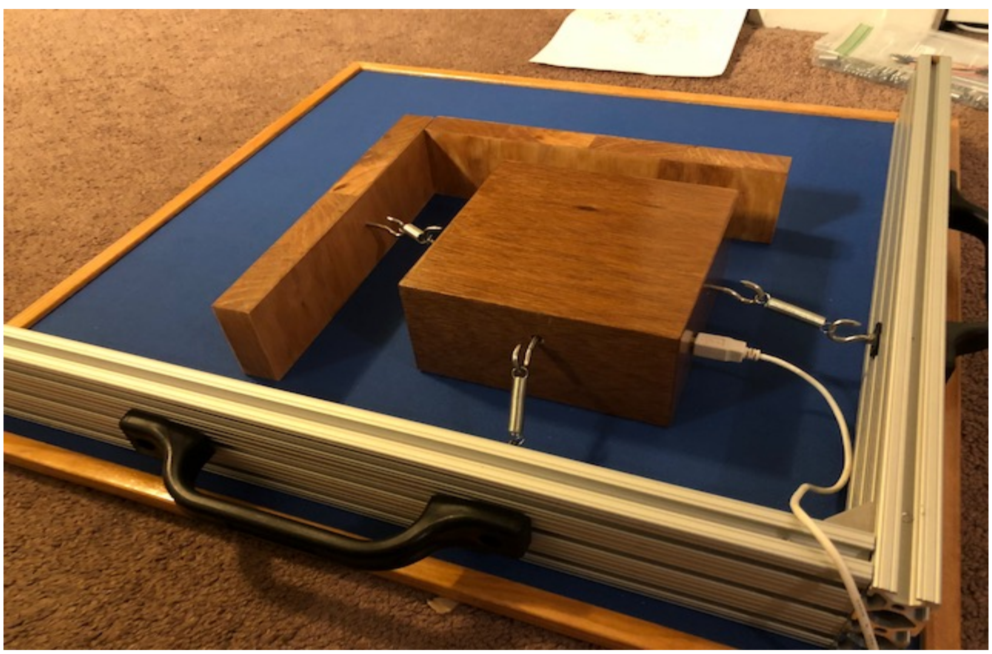


Figure 34: The side view of the system with the USB shown in the side of the box

Advantages

1- An accurate reading for the force applied in the system.

2-An accurate reading data for the displacement with the optical mouse.

3- Blocks added to the both outer springs to prevent errors.

Disadvantages

1-With the technology that the optical mouse has it will be hard to import data to excel without having error.

2- Hard to hack into the mouse.

7.2.6 PROBLEM FOUND

When using the laser mouse, we found out that they are giving us an error each time moving over the frictional surface we have. It gives some data, but the reading wasn't reasonable and huge from what we expected. Furthermore, the team couldn't find any written codes that can be linked directly to the Arduino with those laser mice. The group members did some research to see if we can switch those to something can work with the Arduino and we did. We find a mouse's that called PS/2 mice. There are some people that have used those mice in other project and they do work well with collecting the data. The team decided to use those instead of the normal laser mice, as we found similar codes that we can use for our project. We did all the connection and when we run that through the Arduino, we found out that we are getting one's and sometimes zeros for the mouse reading itself without any reading for the weighing sensors. That probably took 30sec to send the signals which is supposed to be immediately. Moreover, the team also found out when running the codes that both orientations are negative and that's not good, since we need them to be positive. The members think the reason is because of the wires connection are wrong or probably we switched some wrong places when connecting the mouse to the Arduino-UNO.

7.2.7 MOVING FORWARD

The team will try their best to figure out what is the problem with the codes. We will do some research to find other codes so we can try them and hopefully they will work. Members will try to find codes that works for both weight sensors and the PS/2 compatible mouse to combine them all together and get it to work. As for now, we just tested each sensor and they work well. We will try to play around the wires to connect the mouse the other way with the wires to the Arduino to get rid of the negative signs for the orientation. By using the right codes, we could have the right mouse. Last but not least, we will go through the LabVIEW data programming to export all the readings from the Arduino to either Excel or MATLAB. We will stick with the one that is easy to graph for us. We really like Excel because it provides us with graphs that looks exactly like the real-life graphs so it will make more sense for us. Hopefully, we can get everything done before the testing proof date. Below in figure 35 will show all the connection setup for the sensors.

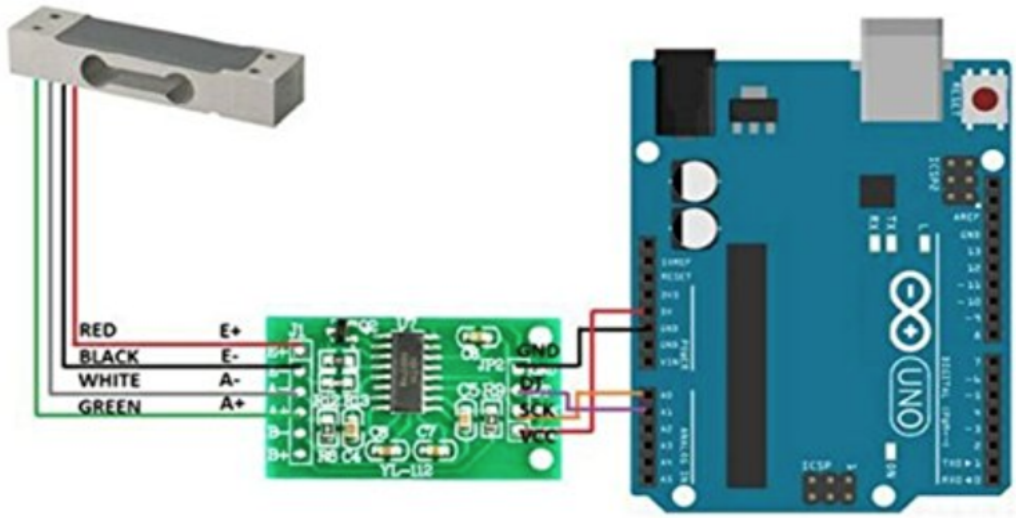


Figure 35: Connection setup for the weight sensor and the Arduino-UNO [11].

8. TESTING

In this section, the team will layout the testing plan and explain why or why not the device has worked as expected. The design requirements will set the standards, comparing test results to these requirements will determine if we met them or not. A discussion of the problems encountered will also be included in this section of the report.

8.1 WEIGHT/POTENTIAL SENSORS

This sensor was calibrated to a known value. To test it, we measured the weight of an apple in a plastic bag and then we hooked the bag to the weight sensor. Whichever value it gave us, we changed it to the value we just took measurements for. That basically based every other reading to be to accuracy of the apple we used for calibration. These sensors were installed inside the center block along the X and Y axis; connected to an HX711 amplifier that made the data readable by the Arduino. A test of the code is then running and force is applied to weight sensors, which then the serial monitor will show live data of the variety of forces exerted. The targeted value for force was being able to withstand up to 10N, but we installed one that can handle up to 5 Kg of force. That is equivalent to 50N, which is five times larger than what we were aiming for. That will increase the reliability and durability of the device, in which the sensors would have a higher life expectancy.

8.2 X AND Y DISPLACEMENT

The displacement was measured using an optical sensor mouse, which was mounted to the bottom of the center block. The Optical mouse is known to take thousands of pictures in a second and translating these values to X and Y. It made the whole block act as a moving mouse across the frictional surface. To test if it giving out data, we connected it to the Arduino Uno board which is installed inside the inner block. A test is then performed by moving the block while running the code with the serial monitor open. While observing the monitor, we moved the block along the X and Y axis and it gave reading for both. Based on how much we delay the code runtime, it gave us number of values. Below in figure 36, shows the output data of the displacement and figure 37 shows the control center of the software.

0.032	0.046	0	112
0.024	0.043	117	-56
0.016	0.036	123	-49
0.010	0.033	88	-58
0.007	0.039	57	-32
0.025	0.045	67	-18
0.021	0.041	-56	4
0.022	0.039	88	47
0.011	0.036	-1	113
0.021	0.034	-1	121
0.018	0.032	-53	110
0.028	0.034	53	25
0.026	0.018	0	0
0.028	0.027	46	-70
0.016	0.036	23	-90
0.016	0.043	0	-104
0.012	0.039	22	-91
0.015	0.029	39	-57
0.002	0.036	-91	-20
0.024	0.035	112	59
0.016	0.04	-1	127
0.036	0.029	-1	107
0.012	0.042	-36	100

Figure 36: Output data for both the force and displacement.

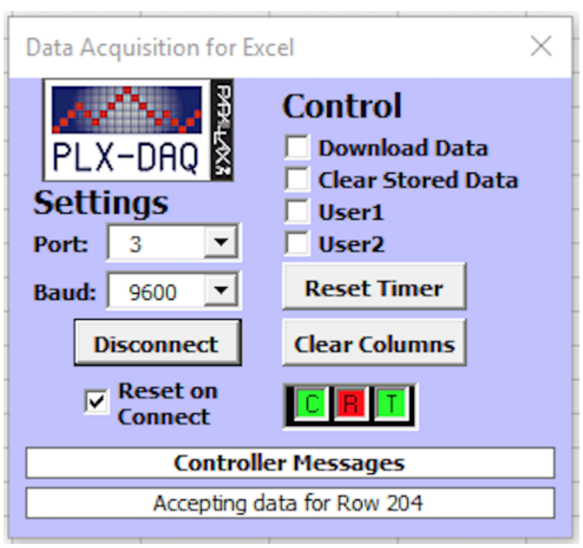


Figure 37: PLX-DAQ Control center

8.3 Frictional Surface

The client didn’t specify a coefficient for friction for the surface, but she needed the center block to stay in place when exerting force on the device. The block should stay in place until the springs expand, then it would move with keeping a constant force until the experiment is done. To do that the team basically used trial and error, where we tried pulling the block on different materials and whichever fits the client's instructions we went with. Below in Figures 38 and 39, you can see the block in place as the spring expand due to friction.

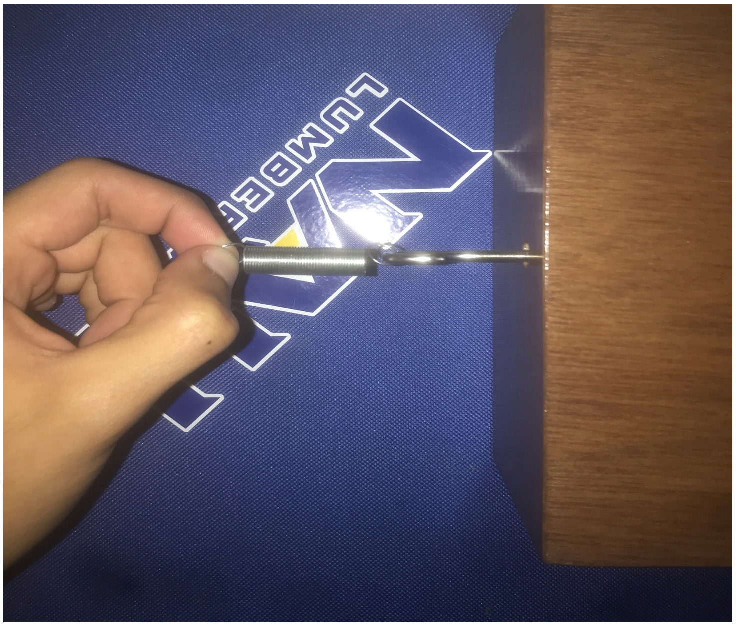


Figure 38: Compressed Spring in starting position

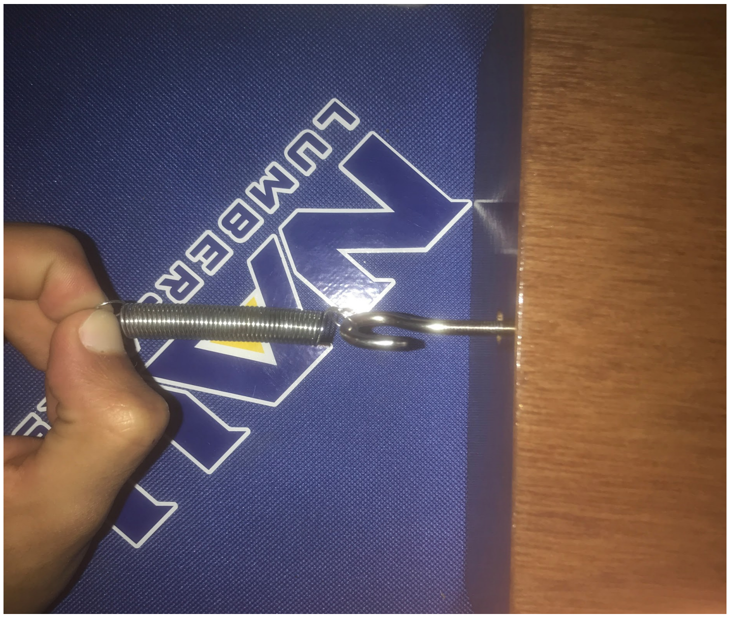


Figure 39: Expanded Spring in same position due to friction

8.4 WEIGHT OF SYSTEM

The team knew from the beginning that the system can exceed 40 pounds. So, we decided to use lightweight materials such as aluminum and wood. The team managed to bring down the weight of the system to about half, we're it weighs 20.8 pounds. Below is a picture of the device on a scale.

Figure 40: Weight of device

Figure 41: Complete device

8.5 Basic Improvements

Some requirements are met by the design itself and the components added on it. For example, making the device easy to carry by adding handles, or adding a rubber sheet to the bottom of device to keep it from moving when in use. In section 7.2.4 of the report, you will see figures illustrating the solution we provided to meet each requirement. The section will show how the device is easy to use and carry.

8.6 Generating Graphs

To generate the graphs, the team used a program called PLX-DAQ, it's free to download. Basically, it's an excel spreadsheet that is compatible to read and translate data from the Arduino to excel. The beauty behind this program that it's easy to be customized by the client to generate any kind of graph, simultaneously. The issue was that the code we wrote before, which gave data for all sensors labeled in the serial monitor, which we had to modify. Simply the data was digital, where we had to add more lines of code that made it possible to label the columns in excel to fit each sensor. To test the device, the team performed the experiment that had to be done by the user and compared the graphs to the ones provided by the client. They didn't match, below you will see the test results of the graphs in figures 42 and 43.

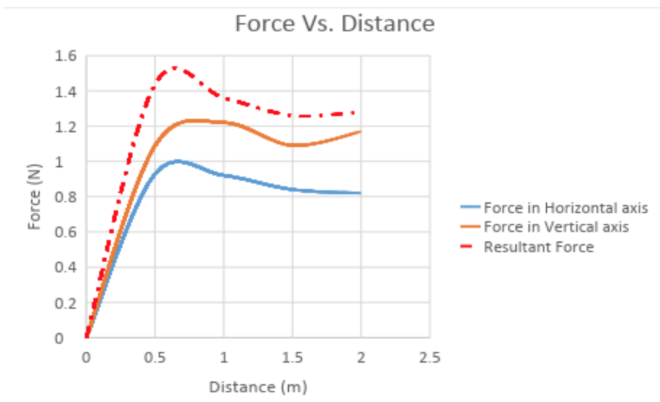


Figure 42: Plot shows how Fx, Fy, and Fr will be drawn when pull the box.

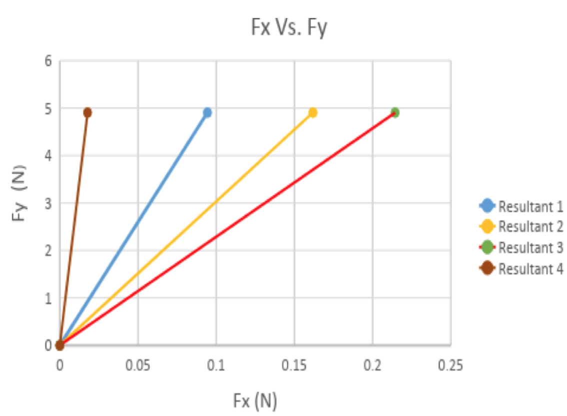


Figure 43: The animation of a multiple resultant force.

The issue was that the mouse readings were too fast for the code, it required many data points. We were expecting the graphs to match because we tested the accuracy of the weight sensors prior to downloading the program. As for the mouse, we tested that if gave out data, and it did. Knowing that they both worked as expected, gave us the confidence that the graphs will be fairly close to the ones asked by the client. As a team consisted of four mechanical engineers, we think that we did our best wiring the device and programing it to give out data. Some members were required to be familiar with new computer language and try to write a sufficient code that will output accurate data points. We think that the issue could be fixed if the team had a member that have the knowledge to modify our basic code to be more efficient and accurate.

9. CONCLUSIONS

In this chapter, we will go over all the experience the team gained during work on this project through the year. As the course is approaching towards the end and we had already worked with the design project and tested it. Now, we will gather all the information we have learned, classes took place that the project teach, and how this project will benefit the graduated students level with understanding the elasticity. For this section, we will be covering the contributors to project success as well as the areas of improvement.

9.1 CONTRIBUTORS TO PROJECT SUCCESS

There are many factors that lead to success the project and moving forward. The most important and effective one was the time managing and planning ahead of time, however the least important was the coast and budget as the team didn't stuck in a certain budget and every time keeps changing as we switched around different kind of sensors. We didn't want over the budget; however, we didn't expect to spend that much.

When we first time met to discuss the project contents and the team charter we put a lot of rules that every member need to follow as well as the team goals that we will achieved. First of all, the team was meeting almost twice a week through all this year. In each meeting, there was an action assigned for each person to do during the meeting for example: Person will be just responsible for researching, someone will be working with the Arduino programming, other will do planning for the design on paper, and the last person will be working with wiring and the materials that need to be used. Those action keeps changing every meeting to ensure all the members are know all the aspects in the project and they are in the right truck when it comes to implementation. Beside our main action that doesn't change for the documenter, project manager, client contact, and the website guy. All the team members were effective, worked hard, and help each other. I will say those contributes make our project success.

Going back all the way to the beginning of the semester when we organized the team charter, it looks like that most of the rules worked well for the entire team and that what's reflect the success we gained by finishing up the project. The team member is met both the engineering and customer requirements for the design and by that they did complete well the goals and purpose stated in the team charter. Members were able to build the wooden box that slides over a frictional surface, the box is surrounded by hooks that carry the springs. By the students moving the box around X & Y directions, it will calculate the student force and distance exerted in the box for both axis. Then plot a graph as the box move for force Vs. displacement. This is basically what we are doing and try to achieve and we did. One of the crucial things, is that whenever someone needs help or stuck with something over the work all the team member tried their best to help him and they were all willing to understand all aspect that goes around the project.

On the other hand, Dr. Oman and the client played a big role on success the overall project and moving forward. We were all mechanical engineers, so we did struggle a lot with learning the CC language, programming, and coding. Even though, we deal with Arduino and after several of researches we come up with the right codes for our sensors. I will say this would be the most negative aspect in the whole project as if there is a member that is major in Electrical engineering with us, we won't have been through many trouble in terms of coding, wiring, and etc. On the other hand, the time managing as mentioned above with the product quality both worked will and consider a positive aspect when moving along the implementation the design. This project involves both mechanics of material and physics classes. When study the elasticity of materials, how does the materials behave under elasticity, and the modulus of elasticity that's for sure will something to do with mechanics of material. However, when talked about springs expansion or compression, kinematic equations, and the compression force. Here is where Hook's law applies and it's define as the negative force exerted on the box when pushing the other side multiply by the distance. This worth for the students to think of when using the design during the class.

There were many problems that the team face during work with the electrical components. First of all, was to understand the Arduino programming and becoming familiar with the CC language. This took us months to get used with the Arduino and to program it with the sensors. Second, the potential sensors were the first thing we set it up. Coming after that the PS/2 mouse which was complicated to get it work with the other sensors. Finally, we found a problem on finding the right program to use to export the data from the Arduino to a MATLAB. We tried the MATLAB first, which make the work even complicated, so we decide to switch to an Excel that give a nice graph closest to the real-life graph. By doing that we decide to buy a new windows laptop as there is no mac laptop can be helpful with installing the program. That increase our budget as explained earlier.

9.2 Opportunities/areas for improvement

We are so glad that this project reflects a lot of useful things, that all the members has benefit from and for sure the students who will use it. I will say the interesting thing and confused at the same time was when dealing with Arduino. At first it was hard because none of us has used it before, some didn't hard about it. After moving along with dealing with Arduino programming and coding we found this is really interested. It's very important for us to always learn something different from our major, that's way the knowledge will expand. To be specific, it's important for us as an engineer to learn about coding the sensors, programming with new software and etc... Now, I can say that members are doing a great job recognize the CC language and I will expect in the future they will do work with Arduino. This was the only and main technical lesson was in our project.

There were many factors that make members like programming with Arduino by time and that was by watching some video through YouTube to learn the basic set up for the program, researching was very helpful and useful for members to deal with coding, and Some electrical professor at NAU that we asked for help. Regarding to the components that we improve it on the design and no one did ask for those, we added handles for both side of the aluminum axis to make the design portable as possible and easy to carry, rubber sheet added at the bottom of the base to prevent the design from moving, and blocks to the end of each spring to prevent errors in data when having the digital values presented. Overall improvements for the design, I will say if we have an additional member in the group that major in electrical engineering thing will become more professional in terms of the current plot displayed.

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11. Appendices

11.1: Appendix A: House of Quality

Customer Requirement	Weight	Engineering Requirement	Compat Design	Weight of system	Frictional Factor	Motion/Force sensor	Length of Sliding Area	Wireless Control distance	X & Y Displacement.	Elasticity	Pushing/Pulling Force	Build Box - material?	Spring Expansions	Durability	Reliability	Weight of Sliding Box
1. Easy to be stored in an office	10		9	3				1				9			3	9
2. Visable from a distance	4		1					1		3		9				9
3. Desktop sized	8		9	3								3		3	3	3
4. Various types of spring	1						3	3	3				9			
5. Portable	9		3	9								3			3	3
6. Easy to carry	6		3	9				1				3			1	3
7. Generate different types of graphs	7					9				9	9				9	
8. Module built	3				3		9	9	9	3		1	9	9		1
9. x&y displacment	5					9	9	9	9	3	3		3			
10. Friction surface	2				9									3		
Absolute Technical Importance (ATI)			211	189	27	108	75	95	75	99	78	198	51	93	150	198
Relative Technical Importance (RTI)			1	3	12	5	10	7	10	6	9	2	11	8	4	2
Target ER values			25"x25"	40 lbs	any -1	1	1m	5m	1m	3ft	10N	4"x4"	1 ft	2 yrs	max	8 lbs

11.2 Appendix B: BOM

Table 1.6: BOM

Part#	Part name	Qty	Description	Functions	Material	Dimenstions	cost	Link of cost estimate
1.1	Stainless Steel	10	Screw Hook Bolt Screw Rings with a Round Screw Hook Lengthened Scr	to hold items	steel	2 in	$6.64	https://www.ama
2.1	Arduino	1	distance measurment module	data of force	plastic	940 nm	$13.99	https://www.ama
3.1	Sukragraha	1	sensor shield V5.0 Arduino Genuino	board for arduino	silicon	3 in by 3 in	$5.49	https://www.ama
4.1	The Hillman Group	195	Small Machine Screws with Nuts Assortment	screws	steel	0.9 x 3.8 x 5.7 inches	$6.49	https://www.ama
5.1	ultrasonic	5	Sensor Distance Module	arduino nano robot	plastic	0.3cm	$9.79	https://www.ama
6.1	Metric	100	M4 hex Nut 304 stainless	for bolt	steel fastener	4 x 4 x 0.2 inches	$7.17	https://www.ama
7.1	Degraw	4	load cell to provide fast, accurate force measurements	cell for arduino	measurment	7.8 mm high, 34 mm wide, 45 mm long	$16.99	https://www.ama
8.1	Keyestudio	1	Auto-switch between external power supply and on-board supply.	for motor supply for arduino	measurment	2.3 x 2.1 x 0.8 inches	$6.99	https://www.ama
9.1	Hiletgo nano	1	draw out the digital	arduino nano robot	convenient and connection	4.7 x 3.8 x 0.5 inches	$5.29	https://www.ama
10	Elegoo	1	super starter kit	tutorial for arduino	plastic	8.3 x 5.5 x 2 inches ; 1.2 pounds	$34.99	https://www.ama
11	programming for arduino	1	starting sketches	192 pages	paper	5.9 x 0.3 x 8.9 inches	$7.99	https://www.ama
12	swordfish	200	extended compressed springs pcs	case kit	steel	8.2 x 4.2 x 1.2 inches	$12.99	https://www.ama
13	laptop	1	laptob that could help us measure the graphs	to help get graphs	technolgy	14.0-Inch diagonal HD	$225.52	https://www.ama
14	Genius Wired Optical, Black PS/2 (DX-110Blackps2)	1	to help move the box	mouse	windows	1.57 x 3.35 x 5.12 in	$6.99	https://www.ama
15	elegoo hc-sr04 ultrasonic module distance sen	1	power supply	inside the box	aluminum	1.8 x 0.6 x 1.2 inches	$11.49	https://www.ama
16	microsoft oem basic optical mouse	1	usb wireless	usb wireless	windows	4.92 x 5.51 x 2.36 in	$11.99	https://www.ama
17	logitech ps/2 optical wheel mouse (not usb)	1	sensor shield V5.0 Arduino Genuino	black usb	windows	4.59 ounces	$9.99	https://www.ama
18	arduino uno r3 microcontoler a000066	1	arduino	base conection	base	6 analog inputs, a 16 MHz quartz	$19.99	https://www.ama
19	AmazonBasics USB 2.0 Cable - A-Male to B-M	1	to conect the box with laptop	cable	cable	6 feet - 1.8 meters	$4.99	https://www.ama
20	DC 5V Relay Module with Optocoupler Low Level Trigger Expansion Board for Arduino	1	single board	board for arduino	base	2.7 x 2.5 x 0.8 inches	$6.79	https://www.ama
21	3/8 female npt magneticaaly latching solenioc	6	dolenoid	battery operater	platic	6v	$16.99	https://www.ama
22	striveday 22 awg hook up wire kit box electric	1	guauge coper	cable	wire	2.28 x 4.33 x 2.28 in	$16.99	https://www.ama
23	breadboard solderless prototype pcb board	3	breadboards for measuring audrenio	board for arduino	plastic	84 x 54 x 8 mm (3.3 x 2.13 x 0.32 inch)	$7.88	https://www.ama
24	northern arizona small decal logo	2	to decorate the design	sticker	plastic	3.75 mil	$16.00	https://www.bkst
25	solo urban hybrid	1	for the laptop, springs and box	bag	bag	15.6	$54.46	https://www.offic
26	spary from sherwin williams	1	yellow color	spray	color	0.04 x 0.01 x 0.01 Inches	$8.29	in paper

11.3 APPENDIX C: GANTT CHART FOR THE SECOND SEMESTER.

	Task Name	Start	Finish
1	Project Duration	01/15/18	04/30/18
2	1st Staff Meeting	01/15/18	01/15/18
3	Individual Post Mortem	01/15/18	01/16/18
4	Hardware Review 1	01/15/18	02/05/18
5	Peer Evaluation	02/12/18	02/12/18
6	Individual Analysis III	02/20/18	02/26/18
7	Hardware Review 2	02/26/18	03/05/18
8	Midpoint Report and Peer Eval 2	03/05/18	03/12/18
9	Staff Meetings Spring Break	03/26/18	03/26/18
10	Draft of Poster and Op/Assem Ma	03/26/18	04/02/18
11	Final Product Testing Proof	04/02/18	04/09/18
12	Poster and Op/Assem Manual du	03/26/18	04/16/18
13	Final Report and CAD package d	04/16/18	04/30/18
14	Peer Eval 3 due	05/11/18	05/11/18