Plasticity Modeling
F6
Preliminary Report

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DISCLAIMER

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1. BACKGROUND

In this section we will be introducing our project. Which is basically is a block box that slides over a frictional surface along X & Y directions, when the student applied force on it they should get an F vs displacement graph with F direction. Also we will be discussing the project description, original system and structure. We will be working on the entire report throw explaining each parts for example, the original system structure. Last but not least, there are couple of equations we are going to use especially with the kinematic equations as we need to get a F (u, v) vs displacement graph at the end of the system process. In this chapter, we are going through the design aspects by discussing the system operation, performance, operation and etc...

1.1 Introduction

In this capstone course, we are challenged to work with a non-profit local project. 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. This project will be used as an educated tool for Dr. Feigenbaum advanced classes for plasticity. So our design should be creative with the idea and easy to deal with for all students. In order to deliver for the students the elasticity theory, we will attach the sliding box with a spring and whenever the student apply a tension or compression on the spring it will immediately graph an output for force vs displacement on both x & y directions. Now student should be able to clearly understand how the elastic limit behave. This project will benefits both the sponsor which is Dr. Feigenbaum and students who studying the plasticity classes as well as the mechanical engineering department they are our primary stakeholders. The major issues we could face in this project is how to connect the sliding box to a device to display for us the graphs we need.

1.2 Project Description

This is an educated local project that helps both Dr.Feigenbaum and her students who are taking plasticity classes. We are going to build a box on different surfaces and attach that box with a free springs and other springs are connected to a fixed frame to explain for the students the behaviors of the elasticity theory. The design should be a desktop sized, small enough to be stored in her office, and seen in the classroom of 20 students as well as easy to carry without extra help. The physical model will be controlled by the student when applying tension (pull) or compression (push) on the spring. After that, the student should get an immediate output graphs for the forces vs displacement in both x & y directions.

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. Purpose of this project is to see how the material behaves after the elastic limit. In this model a spring will connect to the box at from one free end and the other end of spring connects with the fixed support. Box connected with the spring is on slider and box can easily slide 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. So force vs. displacements will measure for it.

1.3.1 Original System Structure

As it has mentioned earlier that the project we are going to build in this semester hasn't been built before and we have searched similar project over the internet but nothing has found similar to our project that's why this project is totally original system and we are not improving any other system. Similar model have built before but those models are not for doing the elasticity measures and behaviors. Such models are just based for spring motions and this model will review the behavior of materials after reaching to their elasticity. So the structure of our model is that there will be a fixed end of a spring and an open end, with the open end connects to the sliding box over the surface. The surface has some friction as well so this is how our model will built.

1.3.2 Original System Operation

There is no other original system then the one we are building in this project so there is no operation for any other system available. And 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.

$$F = F_x i \; + F_y j$$

$$u \; = \; u_x i + u_y j$$

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.

1.3.3 Original System Performance

There is no original system so we cannot find any performance for any original system. The original system is the one we are building so we cannot mention any original system performance unless our system will build. Furthermore our system being the original system will do the analysis on the behavior of plastic materials elasticity.

1.3.4 Original System Deficiencies

For our project, we had to come up with an original idea that satisfy the client's requirements. It was hard to know what the deficiencies are in the system, since there is no original system. All we know, is that the hard part and the most important one is to generate a graph, and we need to make sure that they are no deficiencies including that part.

2. REQUIREMENTS

The design that we are going to build is basically are going to use for student who are taking the advanced classes for plasticity with Dr. Feigenbaum. We will divide every part for example customer requirements, engineering requirements, testing procedures and house of quality. Couple of the requirements are difficult because we must give our client the best design that will be good to provide for her students. She wanted a design that grab the attention for her students in the classroom.

2.1 Customer Requirements

Customer requirements is important in our project. Without the customer requirements we couldn't think for a design. For example our client is looking for couple of specific things such as desktop size design and a design that can be seen by 20 students in a large room. Also she is looking for a design that she could hold it in one hand and she could store it in here desk. The table below show each customer requirements.

Table 1.1: Customer Requirements

Customer Requirements	**Description**
Desktop sized system	It means a small to medium design device
Large to seen in the classroom of 20 students	Design with a good shape
Small to store in an office	Good size that is not very large
System will control by user	A force done by human
System must work in both tension and compression	There must be conection
User can change the direction of force at any point during loading	By the frictional force
Tabletop model	A design that is good to be a size of a table.
Multiple frictional surfaces	Means by multiple users

2.2 Engineering Requirements

Engineering requirements are the one on which this project will built. These requirements focuses on the actual components of system and their targeted values. These values will help in building the project because there will be our targeted values and while selecting the design, implementation the design ideas, these targeted values will kept in mind so it will be easy to develop different ideas and it will easy to select the final design on the basis of these requirements and targeted values. Engineering Requirements for the project is listed below in Table 1.1.

Table 1.2: Engineering Requirements

Engineering Requirements	**Targeted values or Tolerance**
Spring Expansions	0.3048 m
Elasticity	0.9144 m
Pushing Pulling Force	10 N
Frictional Factors	1
Weight of system	18 Kg
Length of Sliding Area	1 m
Wireless Control distance	5 m
Weight of Sliding Box	2 Kg
X Y direction displacement	1 m
Durability	2 years
Reliability	90% success rate.

We didn’t find any difficulties with the cost of our project. We will be using materials that are easy to use and also will be valuable for graduate level classes. Our client is looking for a design that is easy to use and also light. That she can hold it with here everywhere.

2.3 Testing Procedures

As the engineering requirements have defined so it becomes necessary to test the engineering requirements before proceeding for the further design analysis because if the engineering targeting values are wrong or not achieving or crossing the limit then we must change these values before moving on. Therefore different sort of testing procedures will apply for different requirements. And these testing procedures have mentioned below.

2.3.1 Spring Expansions

Testing of spring expansion can be done by hand by simply expanding it and compressing it by placing a scale by the side of it and determine how much it is expanding and how much it is compressing. If the compression is long or expansion is long then we need to change the targeted values.

2.3.2 Elasticity

Elasticity of the material can also determine in the same way by making a holder of same material so that it can hold and stretch through two hands or there is a machine available for stretching so place the material inside that machine and determine its elasticity. Elasticity of any standard material is available online as well in order to verify.

2.3.3 Pushing and Pulling Force

Pushing and pulling force can determine through a force detection sensor. This sensor can determine a force apply by a human being. So a person who will push and pull the box in this project will apply the force on this machine and will determine whether the force mentioned is correct or need to make some changes in it.

2.3.4 Frictional factor

Frictional force can determine by the friction factor and friction of any material is available already. So the friction value can obtained online and then using the formula to calculate the frictional force.

2.3.5 Weight of a system

This is the overall weight of a system and the limit of this weight is that value a man can easily hold so to test this value any weight of same size will hold by human and he will walk around to see if it is easy to carry or not.

2.3.6 Length of Sliding Area

Sliding area length is standard size and it can check through any slider that is it enough or short.

2.3.7 Wireless control distance

Wireless control distance can determine by specifications mentioned on the controller.

2.3.8 Sliding Box weight

Box weight can test by placing a box of different weight over the slide and see the sliding capability of each weight.

2.3.9 X Y Direction Displacement

This is the displacement measure, and it just need to check by moving the box over the scale that it is giving the correct value or not.

2.3.10 Durability

Durability can test by simply reading the specifications of each part and determine the lifetime of each part.

2.3.11 Reliability

This can test only by seeing the specifications of each part that is reliable or not.

2.4 House of Quality

Quality, which in this case refers to meeting the needs of our client. The House of Quality (HoQ) basically show the correlation between the customer and engineering requirements. The customer requirements comes 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

Our existing design is to build a sliding box that works in both X & Y axis. That box should be attached in 2 springs on a frictional surface. As one spring will be used to pulls or pushes when a student apply a force on it. The other spring will be connected between the sliding box and a rigid wall. The student will get an immediate plot for force versus displacement depend on the axis that he/she applied the force on. The design will be unique and creative so it can deliver for the student how the elasticity behave. So in this chapter will go over the system & subsystem design and as the design will be used as an educated tool for the students we will consider it from the STEM that involves all science, technology, engineering, and math.

3.1 Design Research

Several researches have been made for the plasticity modeling and finally we have come up with UCAR as well as Mechanical department to be our benchmarking. This design will be explained for student that taking Dr.Feigenbaum advanced classes in plasticity. This design will be doing from scratch as we don't have any previous designs made for plasticity. When we look over the UCAR cite we saw different design made as a teaching box for the student in the classroom, and we saw how well they understand when using those teaching box. “UCAR Center for Science Education Teaching Boxes are themed collections of classroom-ready educational resources to build student understanding of science, technology, engineering, and math (STEM). Resources highlighted within teaching boxes are developed from UCAR Center for Science Education and other credible education programs, and have been vetted by the Center's education team.”[1]. We are not going to really find any issues, because all the designs was helpful to give us a good start with our sliding box design and as long as they are under STEM they helped us with the idea is how to make the students be an interactive with teaching box. This benchmark which is the UCAR was benefits with giving us a good ideas of the teaching box and how to be a great with a design so the student will be interactively with it and understand the process going on right away.

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 especially 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 o 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 case of extreme cases of friction i.e. a lot of friction or less friction. This means that during building and construction and manufacturing of various products their tensile strength should be considered so as to avoid occurrence of 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. In case a very heavy load is hanged on the spring balance the spring will stretch until its elastic limit is reached. The spring results into an irreversible deformation.

3.2.1 Existing Design #1: Elastic

This entails an ideally elastic perfectly plastic model whereby a spring is fixed on a block and then pulled along a surface. The spring stretches as the block resist moving. Once the spring is fully stretched the movement becomes constant. This model is significant and it is one of the most successful plasticity models. In this model requires a single experimental input is required i.e. 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 been 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].

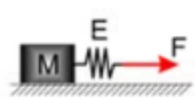


Figure 2: figure that shows the yield strength [2]

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, γ=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 [3].

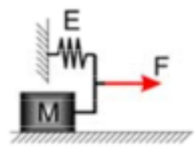


Figure 3: Shows the strength [3]

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 stain is distributed equally between the two springs and 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 [3].

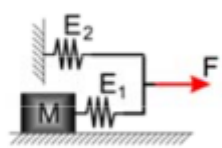


Figure 4: is the design elastic work [3]

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 don’t want use to use the Z axis. The frictional surface whether be high or low. Lastly, we are going to use 2 kind of sensor one to measure the distance between the block and the rigid wall, other to measure the speed for the user.

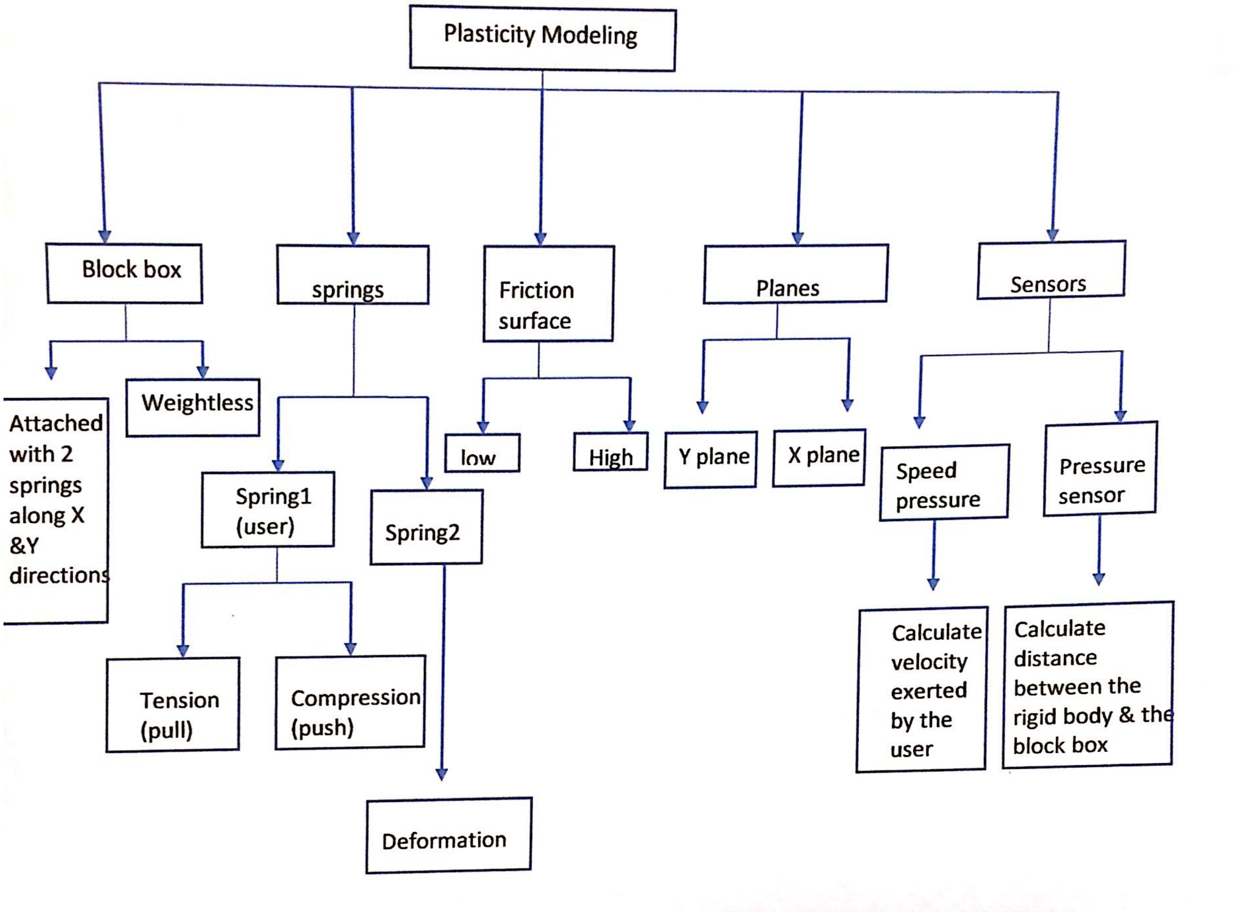


Figure 5: Functional decomposition for our design.

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 plot a graph as an output. Below in Figure 6, is the Black Box Model.

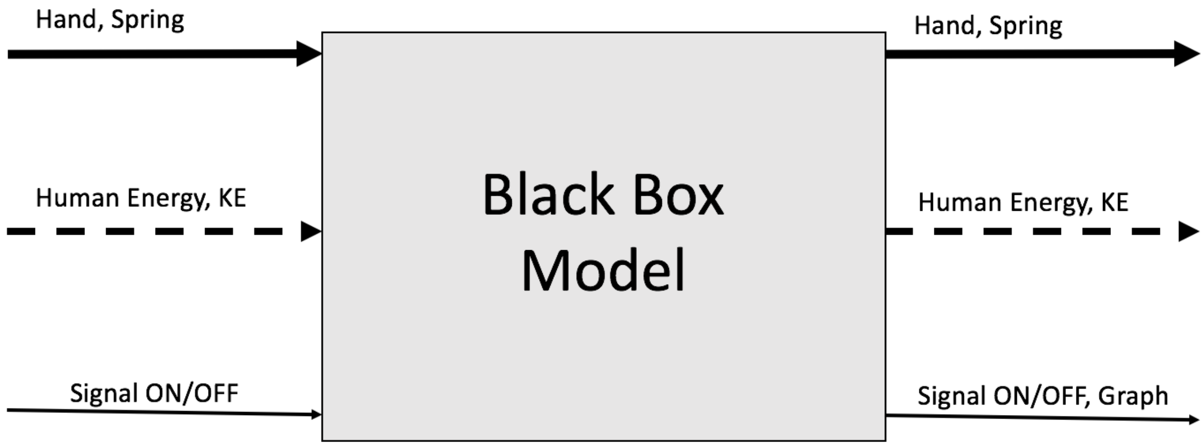


Figure 6: Black Box Model

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

This functional model is breakdown in a way that clearly shows how the design is being work and in each step it shows what is the energy 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 led 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.

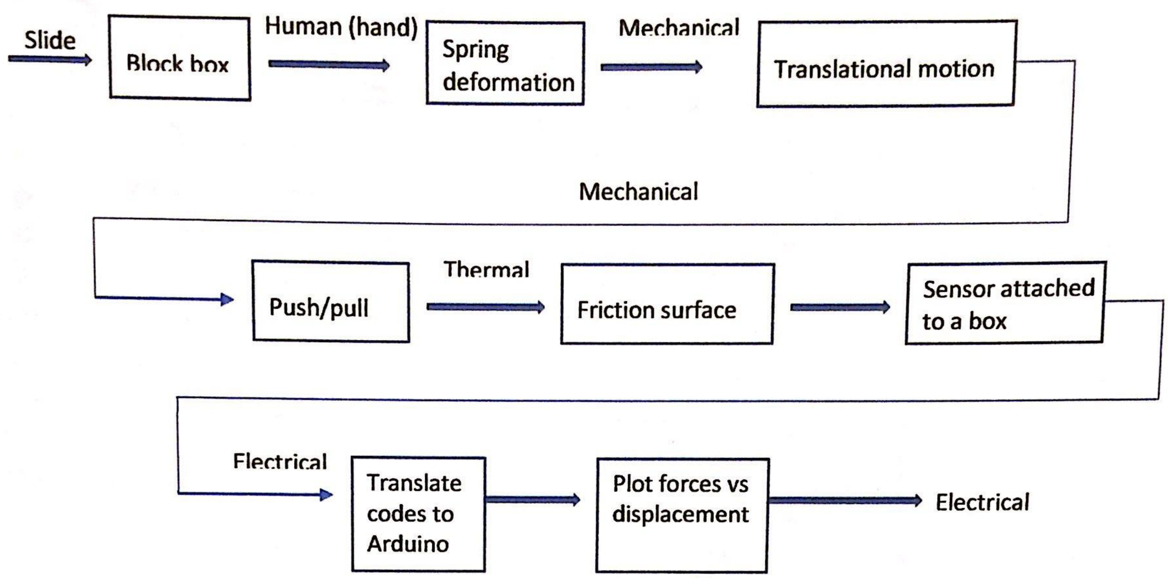


Figure 7: Functional Model

3.4 Subsystem Level

The subsystem level is important in our project. Without those components we couldn't build our design. Around ten system level we are going to use to create the plasticity design. Our client gave us couple of things that she is looking on the final design such as Arduino, microcontroller, springs and etc. 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 it inputs the codes that we will be doing on the MATLAB. Applying Arduino codes set up is 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 got the final testing.

The table top display shows the final numbers and forces that we calculated on the design. How it will not fall it will be on a specific weight that the client will be able to hold it in one hand and she can use it for everywhere. Displaying outputs is 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 Fx vs u, and Fy 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 do 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

It would be all about if the user pulls or push the spring whether it 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 then apply to get the 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.

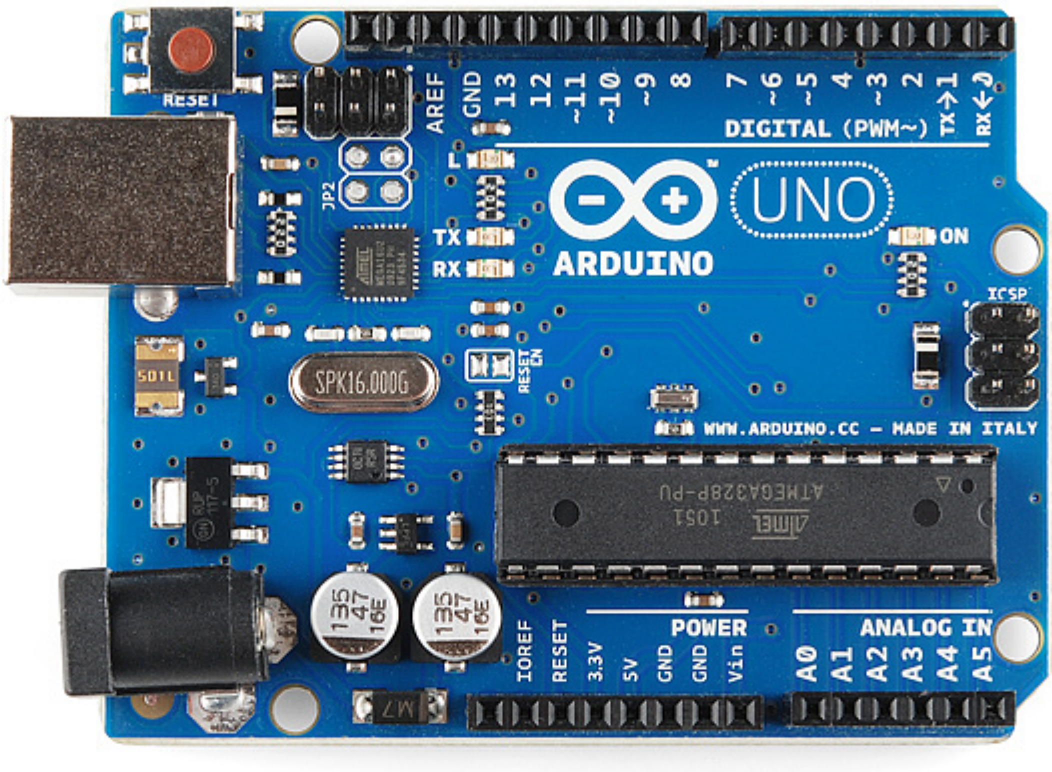


Figure 8: Arduino Uno [4]

3.4.1.2 Existing Design #2: Sensors

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

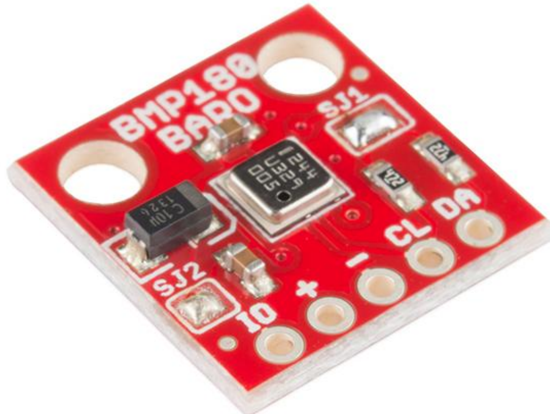


Figure 9: The below figure will show a full connection of how to setup the speed sensor with the Arduino [5]

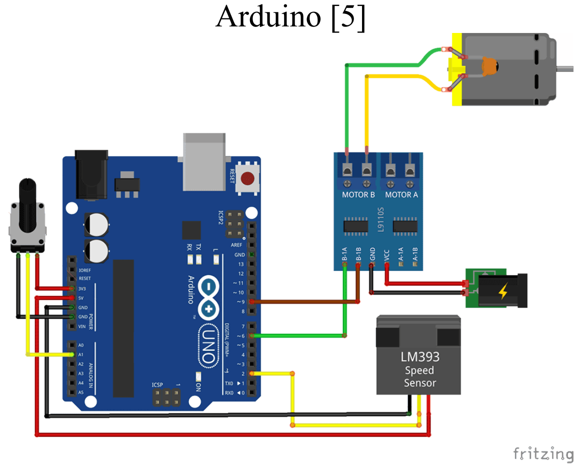


Figure 10: Shows the connection between the LM393 & Arduino [6]

3.4.1.3 Existing Design #3: Kinematic equations

Those 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 $F = ma$
Velocity equation $v = \Delta m/t$
Acceleration equation $a = \Delta v/t$

Kinematic equations to solve for the displacement:

$$d = vi * t + \frac{1}{2} * a * (t)^2$$
$$(vf)^2 = (vi)^2 + 2 * a * d$$
$$vf = vi + a * t$$

Figure 11: Kinematic equations done by Nawaf Alkhalaf

3.4.2 Subsystem #2: How does it Not Fall

The subsystem is important to our project because it's a device and it must not fall. As our client and our department sponsored they indicated that they don't want something easy to fall. They wanted a design that can be provided for a graduated level senior's class.

3.4.2.1 Existing Design #1: Safety

We are required to create a design that is secure and safe for the customers. A design that our client can hold it and walk through anywhere. The safety requirements are creating a design with useful products that can help the customer not to get hurt.

3.4.2.2 Existing Design #2: Easy to carry

The design of the system must not exceed 18 Kg in weight. Our client is looking for a smaller shape that is easy to carry. The box itself must be at least 2 kg, so it has some sort of gravitational resistance when force applied from the client/students.

3.4.2.3 Existing Design #3: Shape

The shape of the design must be meaningful for example a design that will grab the customer attention with colors. The shape must be easy to see and hold a medium size shape. It should have hooks all around, where students can add/remove springs on demand, which makes it module. The system should also be a tabletop design, which can easily be stored away.

3.4.3 Subsystem #3: Microcontroller

The microcontroller will be used in our design so we can build the device that our client wants. It will be embedded to the sensor and the Arduino which will complete the setup of the system. It is cheap but also significant to the success of our project eventually.

3.4.3.1 Existing Design #1: Code

The code will be applied on the flat surface of the microcontroller. Since it will be connecting to the Arduino that will help getting the codes through the MATLAB program. The team must write a code that will plot a graph of the force applied by the user versus the displacement of the box. A code also be written to display the graph on a screen or a connected computer.

3.4.3.2 Existing Design #2: Flat Circuit

The flat circuit is one of the important things in the microcontroller for example it will help to get the exact data of our design. It will be calculated when we create our design. It relates to our requirements because we need to build a design that can be used to multiple users. Eventually, it helps with the data precision and accuracy of the readings.

3.4.3.3 Existing Design #3: Board

Board is the first step in creating a microcontroller. It adds all of the other requirement for the project for example sensor, shape and the battery. It's basically where the electrical components are attached and stored away from the user. Any damage to this board can cause the whole system to fail, so this needs to be covered from dust and liquids. Below in Figure 12, is an example of what a board looks like.

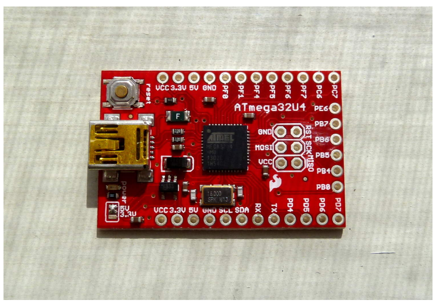


Figure 12: The figure shows the bored of the microcontroller that will be used.[7]

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 one from both sides and the second spring is open from one end. In this way the box will move with the help of spring by stretching the spring. And the displacement covers by the box will record in the system through the help of Arduino controllers. And then the controller and system will generate the graph of force vs. displacement. Here is the module showing below in the figure 13.

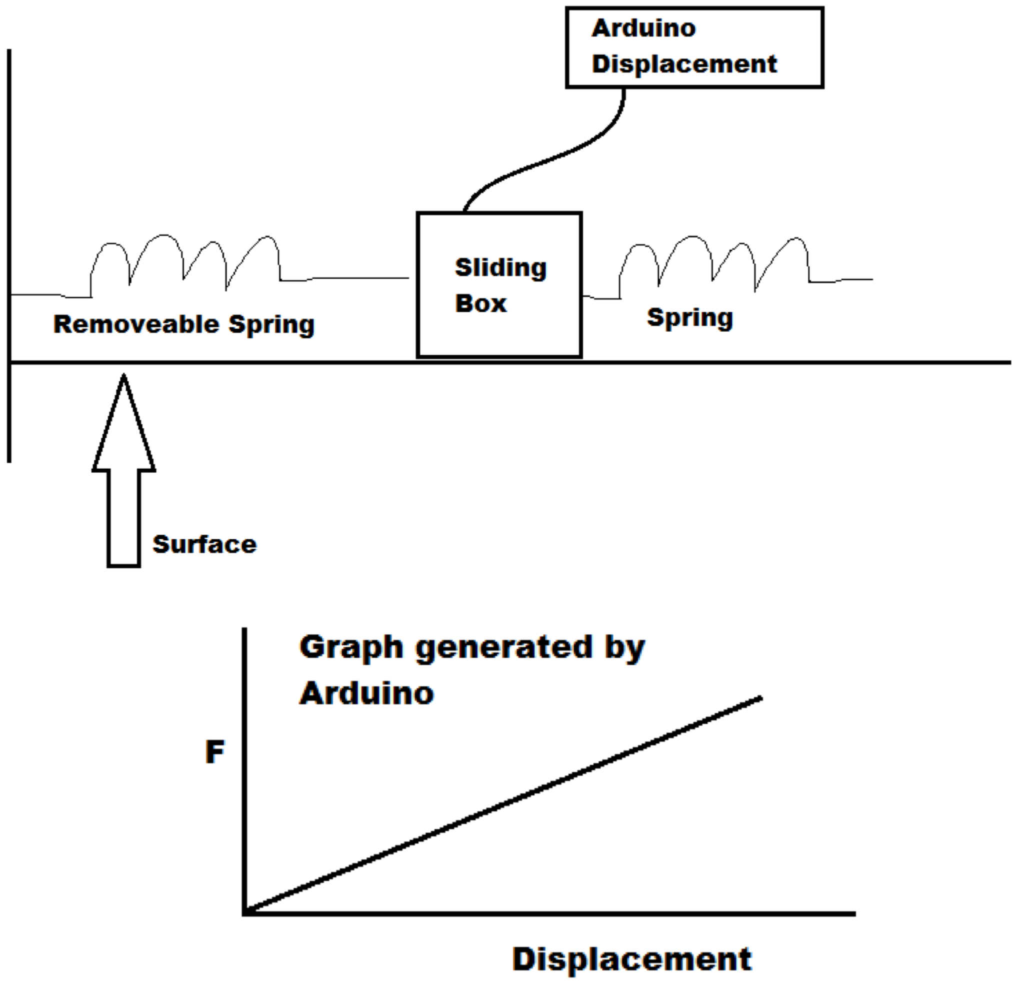


Figure 13: Basic Module

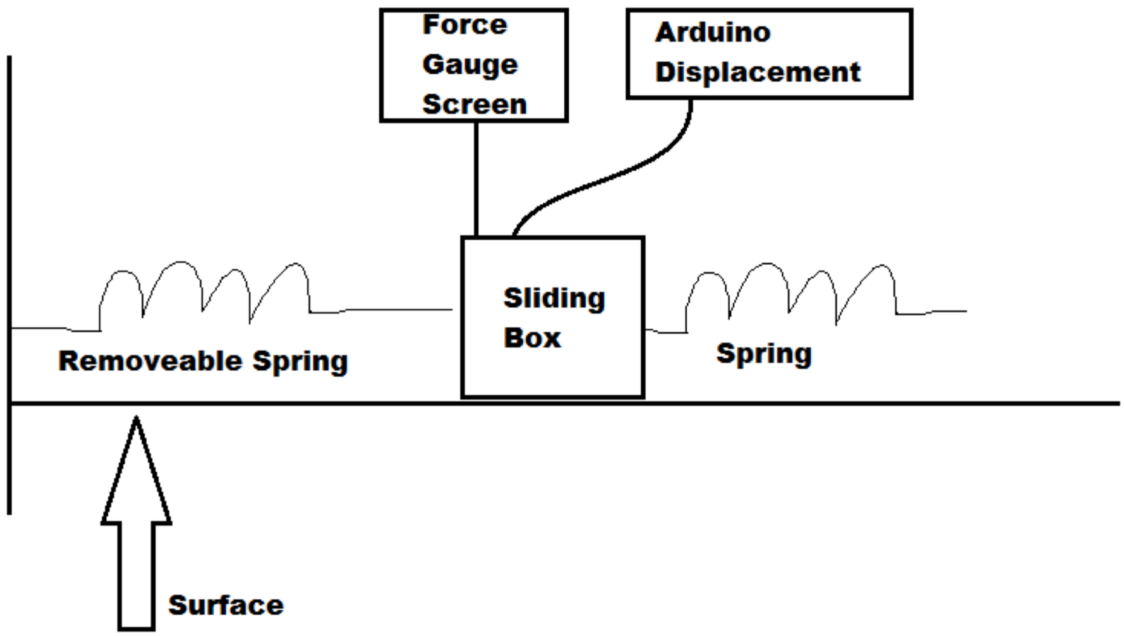
Advantages
Following are the advantages
1. Removable spring can make it easy to adjust and slide over the surface.
2. Spring elasticity will not affect material elasticity.

Disadvantages
Following are the disadvantages
1. For drawing force vs. displacement curve we need an extra computer screen to draw and show the curve.
2. Processing will be slow because of extra screen attach 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 determine through the screen continually. And remaining removable springs have attached as well which can remove at any instance. This design is showing below in the figure 14.



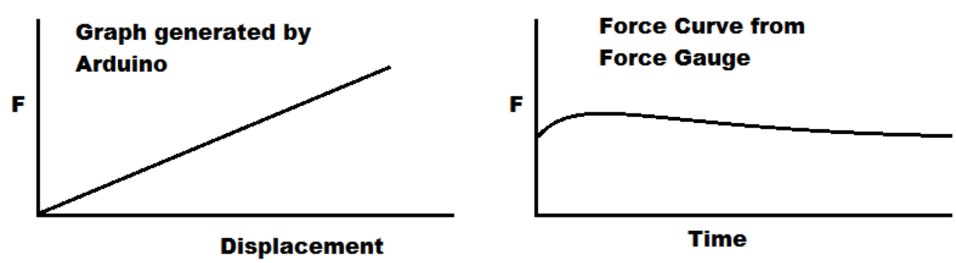


Figure 14: Simple Module with Force Gauge

Advantages

Following are the advantages for this design system

1. Force curve is available so force will monitor continually and it can vary eventually
2. Removable spring can make it easy to adjust and slide over the surface.
3. Spring elasticity will not affect the elasticity of material

Disadvantages

Following are the disadvantages

1. Force .vs. displacement curve will form by the system which makes the system slower
2. Will not portable

4.3 Design # 3: Force and Spring Gauge with simple module

This is another design in which two gauges have added in the system. One is 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 as well. Following is the figure showing the design idea.

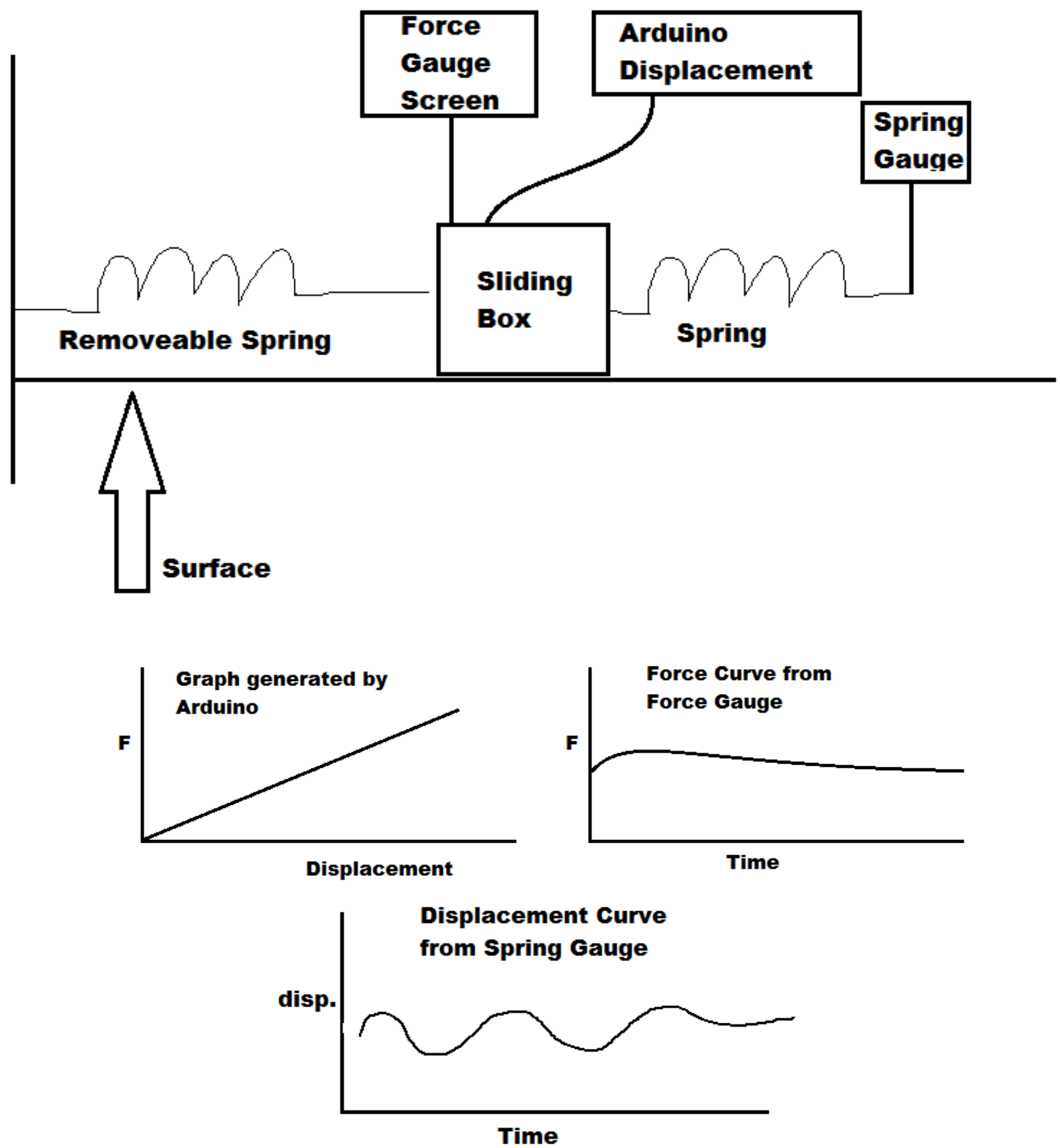


Figure 15: Simple module with force and spring gauge

Advantages

Following are the advantages of this system

1. Displacement and force curves will monitor through the gauges.

2. Easy to understand the material behavior from the live gauge results
3. Removable spring can make it easy to adjust and slide over the surface
4. Spring elasticity will not affect the elasticity of material
5. Portable system

Disadvantages

Following are the disadvantages of system

1. 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.

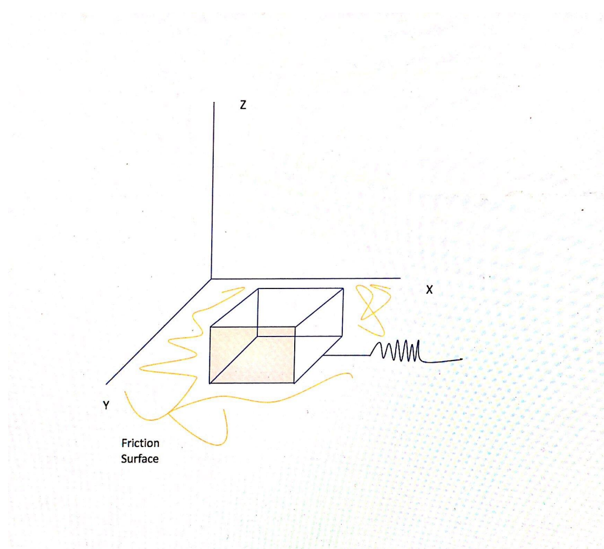


Figure 16: Box sliding over frictional surface.

Advantages

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

Disadvantages

1. The frictional surface can be dangerous to user.

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 show how we used walls to act as a resistance force, which also makes things more interesting when studying the elasticity of a certain material.

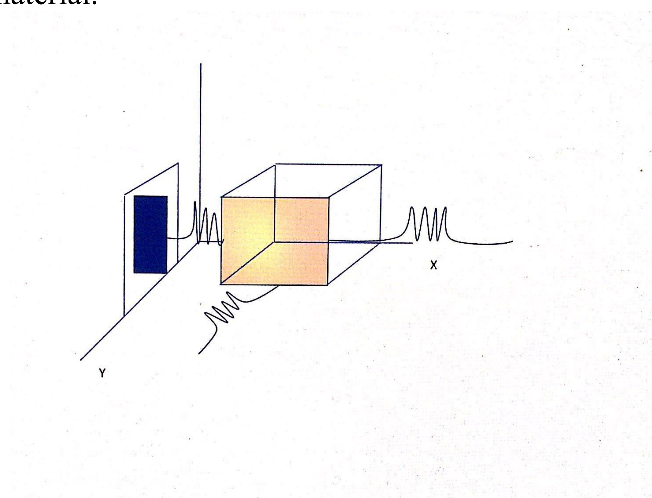


Figure 17: A box with spring connecting to the rigid wall

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.

4.6 Design # 4: Box connected with a spring & the rigid body is connected on the z plane

This design shows the force how is 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 will also need to be replaced after a trial.

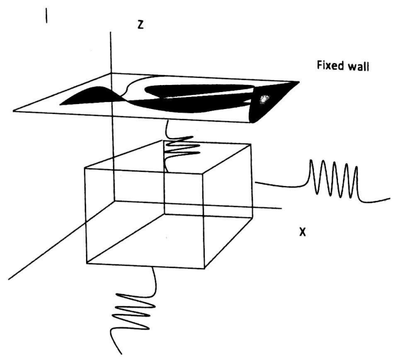


Figure 18: A box connected with a springs along X & Z axis

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 search about. This section talks about 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. Also the decision matrix is an important part in this section which have the weight, frictional link and etc. This section will narrow down our options into our final design selected.

5.1 Rationale for Design Selection

Purpose of this project is to understand the elastic behavior of materials after they reached to their elastic limit. For this purpose we are building a product which can read the behavior of 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 few design ideas have presented in the previous section and in this section we are finalizing the design idea and selecting the one which will implement in actual. In order to finalize the design ideas we have used two different techniques first one is Pugh chart and second one is decision matrix.

5.2 Pugh Chart

Pugh Chart is a type of chart which determine if the engineering requirements and client requirements are fulfilling in the idea or not. Those ideas which are fulfilling the requirements will then selected from it. For this project we have selected top two ideas from Pugh chart and these two ideas are:

1. Simple Basic Module.
2. Force Gauge with Simple Module.
3. Force and Spring Gauge with Simple Module.
4. Box sliding over frictional surface.
5. Box attached with a spring all connected to a rigid wall.
6. Box connected with a spring & the rigid body is connected on the z plane.

Above six designs have narrow down from the Pugh chart because the first three designs have gauge screens which is giving benefit to plot force vs. displacement graph. And design number 3 has portability advantage as well that's why these two designs have narrow down for final result. The rest of the design will be using a sensors to be able to do all the calculations needed to translate them into the Arduino. The next step is to put these results in decision matrix to narrow down the result. Below will be a table that describe the Pugh chart for our designs.

Table 1.3: Pugh chart

CN's VS ER	System weight	Design1	Design2	Design3	Design4	Design5	Design6
Weight of Sliding Box	8	+1	+1	+1	D	-1	+1
Frictional Factors	1	-1	-1	+1		+1	-1
Length of Sliding Area	1	-1	-1	-1	A	+1	-1
Spring Expansions	3	-1	+1	+1	T	-1	+1
Elasticity	0.9144	+1	+1	+1		-1	+1
$\Sigma+$		2	3	4	U	2	3
$\Sigma-$		3	2	1		3	2
Total		5	5	5	M	5	5

5.3 Decision Matrix

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

1. Force and Spring Gauge with Simple Module

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

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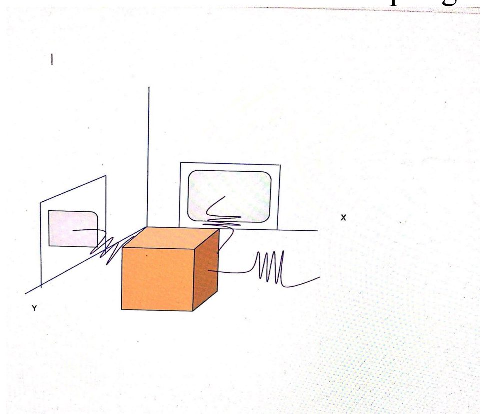
7. Appendices

7.1: Appendix A: House of Quality

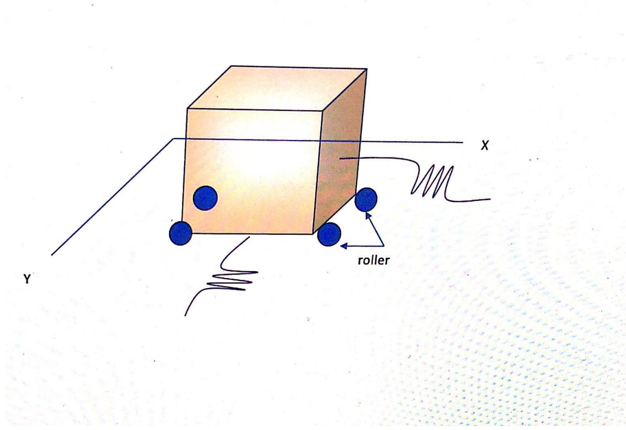
Customer Requirement	Weight	Engineering Requirement	Compat Design	Weight of system	Frictional Factor	Motion/Force sensor	Length of Sliding Area	Wireless Control distance	X & Y Displacement.	Elasticity	Pushing/Pulling Force	Build Box - material?	Spring Expansions	Durability	Reliability	Weight of Sliding 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
Tolerances of Ers																
Testing Procedure (TP#)																

7.2: Appendix B: Including the rest of the designs from section 4

- Design7: Box is attached with three spring connected to rigid walls



- Design8: A box with four rollers sliding on a frictional surface



- Design9: A box is sliding to the wall and the pressure sensors is calculate the distance.