Final Design

EML 4551C – Senior Design – Fall 2012 Deliverable

Team 13: Smart Materials Museum Exhibit Design

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Executive Summary

The Smart Materials Museum Display design project will produce an interactive display with the ultimate goal of teaching the Tallahassee community the science behind smart materials and how they are used in engineering applications. The Challenger Learning Center is an aerospace themed facility that promotes interest in science, math, and engineering technologies by providing interactive learning experiences including a Space Mission Simulator, IMAX® 3D Theatre, and the Downtown Digital Dome Theatre & Planetarium. The target audience of this project is school aged children, so the display must be interactive and entertaining, as well as accomplish the ultimate goal of facilitating education of the interesting properties of smart materials.

This design utilizes the properties of piezoelectric smart materials to control and guide the projection of a laser light onto a large map of Florida displayed in Challenger Learning Center's lobby. This laser signifies communication from outer space to various Florida cities. The path of the laser light will travel from a user interface to a satellite and then be redirected from the satellite onto the map. The project can be separated into two portions, one being the user interface where a joystick will be used to control the reflection of the laser light, and the other being at a satellite where the assumed communication will be coming from.

A joystick coupled with an arduino and two amplifiers will be connected to two separate macro fiber composite piezoelectric materials and will be used for the initial control of the laser light path. The light will be aimed from this interface to light sensors at satellite structure. The output from the light sensors will be sent into a second arduino which will control the servos of a pan and tilt kit. A second laser will be mounted on top of the pan and tilt and will shine onto the map and signify the "communication". The idea behind this project is to stimulate the operator's interest by creating a game out of the display. The display will be interactive and entertaining, as well as educational.

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1.1 Acknowledgments

Our team would like to thank our advisor Dr. William Oates of the FSU-FAMU mechanical engineering department for assisting us throughout the project. Also, we would like to thank Ms. Susan Borland and Mr. Harry Hawbecker of the Challenger Learning Center for consulting with us throughout the planning and execution of the project.

1.2 Problem Statement

The goal of this project is to build a smart material museum exhibit that is interactive, as well as informative. Smart materials have a tremendous number of uses today, and yet a majority of the public is unaware of their utility. This project aims to increase public awareness of these materials, while providing the Challenger Learning Center with a new museum exhibit to attract visitors. The exhibit should be simple enough for grade school students to use and understand, while being safe and robust enough to stand up to repeated use. The exhibit should be completed and ready for display at the conclusion of the senior design project.

1.3 Operating Environment

The museum exhibit will be displayed in the Challenger Learning Center, located in Tallahassee, Florida. The exhibit was first planned to be placed inside the facility's mock NASA mission control room. This control room is used to conduct mock NASA flight missions; simulating events such as launch, flight emergencies, and landing. The idea was to implement our project as part of their "Mission to Mars" program that they have students complete. Upon presenting our design concepts to Mr. Hawbecker, it was determined that our design would be much more impressive if done on a larger scale. Therefore, it was decided to place our exhibit right outside the mission control room in the Challenger Learning Center's lobby.

1.4 Constraints

1.4.1. Budget: The budget is currently at $1500. We are well below that limit as our most expensive items such as the piezoceramics and the amplifier are being donated by the FAMU/FSU College of Engineering.

1.4.2. Interactivity: We want our exhibit to be entertaining and user interactive.

1.4.3. Safety: The exhibit must be safe for use with kids as young as kindergarten. No exposed electrical hazards or other potentially dangerous mechanical devices.

1.4.4. Theme: We want it to be related to space/NASA so that it goes hand in hand with their current program for students.

1.4.5. Audience: Though we want to inform the whole general public on the use of smart materials, we are specifically gearing our exhibit to 5th to 8th grade students.

1.5 Piezoelectric Materials

The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and electrical state in crystalline materials with no inversion symmetry. Essentially converting force into electricity (voltage), or the reverse electricity into force. A voltage can be applied through an amplifier and that voltage will cause the piezoelectric material to change shape. This project will use this property to control the path of a laser light source. At low frequencies the relationship between an applied voltage and the mechanical stress induced can be calculated using the following equations.

1) $E = -(aT)$;   with a = piezoelectric voltage constant, T = stress on material
2) $Q = -(bF)$;   with b = piezoelectric charge constant, F = applied force

As mentioned earlier, dimensional changes can also be a result of applied electricity and can be determined using:

3) $\Delta h = bV$;   with Δh = change in height or thickness, V = applied voltage
4) $S = bE$;   with S = strain, E = electric field

Piezoelectric sensors are also available that use the piezoelectric effect to determine the electrical charge produced by an applied pressure, strain, or force.

If the ceramic is exposed to an alternating electric field it would change its dimensions cyclically at the frequency of the electric field. A resonance frequency will be reached when the oscillations reach a frequency when impedance is at a minimum. This is also the frequency at which the piezoelectric material is most efficiently converting the applied voltage into mechanical energy. When exposed to stronger magnetic fields, depolarization will take places.

This generally occurs when voltages are between 200 and 500 V/mm or greater. Another limitation to piezoelectric materials is amount of applied mechanical stress, as it can alter the alignment of the material's dipoles.

The piezoelectric material utilized in this project is called macro fiber composites (MFC), produced by Smart Material Corporation. The MFC consists of rectangular piezoceramic rods sandwiched between layers of adhesive film. Voltage is transferred to and from rods within the materials via tiny electrodes in the film. MFCs are available as either an elongation type (Figure 1a) or a contraction type (Figure 1b) and each can be used to produce translation, bending, or torsion dependent on its attachment to its base material.
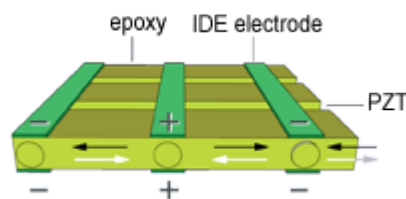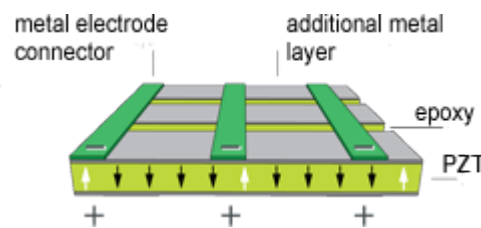
Figure 1a   **Figure 1b**

1.6 Smart Material Applications

The inspiration behind our exhibit design was based on the fact that smart material is used in space today. They are used in adjustable antennas for satellite communications. The smart material used in this is of the piezoceramic type, which is the same that we utilize in our exhibit. Self-adjustable antennas are possible when piezoceramic patches are attached to the back of a reflector. When this piezoceramic is given voltage, it expands and since it is attached to the reflector, it bends its surface as well. With the surface bending, the overall shape of the structure can change, which alters the properties of the antenna itself. Changing the shape of the reflector while in orbit can improve its signal quality. Doing all this with piezoceramics is quite the upgrade, as all that has to be done is apply the proper voltage. Prior to this, the whole mechanism beneath an antenna would have to be moved to change communication direction.

Section 1: Introduction

Our exhibit is not a direct representation of this application in space, but it is very similar. Piezoceramics are used as part of the design to adjust a satellite. Once the satellite is adjusted, communication can be made with a different part of Florida, as will be shown on the map. The main concept that is to be portrayed by our exhibit is how piezoceramics can be used to in satellite communications.

Section 2: Concept Generation

2.1 Concept 1: Laser Manipulated Robot- Laser Guided "Curiosity"

2.2 Concept 2: Satellite Transmission Game

2.3 Concept 3: Laser Activated Satellite Control

2.4 Concept 4: Mars Curiosity Rover "Chem-Cam"

2.5 Decision Matrix

2.1 Concept 1: Laser Manipulated Robot- Laser Guided "Curiosity"

One of the most talked about missions currently going on at NASA is their exploration of Mars with the rover Curiosity. Since the Curiosity landed on Mars in August, 2012 the unmanned rover has been working to discover if there ever has been or could be life on the orange planet. The basis behind this idea would be to use the direct or indirect laser control to manipulate the movement of a robot. The Robot would have the appearance of the Mars rover Curiosity and the display would resemble the surface of Mars. The students would use the joystick to guide Curiosity through a maze on the ground in the display.

There are three methods that could be utilized to guide the path of the robot with the laser light. The first is using photoresistors as the eyes of the robot. Phototransistors are a light-sensing device that can be used to provide analog or digital signals. Phototransistors can be used in the programming of light following robots because they can detect visible, ultraviolet, and near infrared light. The basic phototransistor circuit is shown in Figure 2.
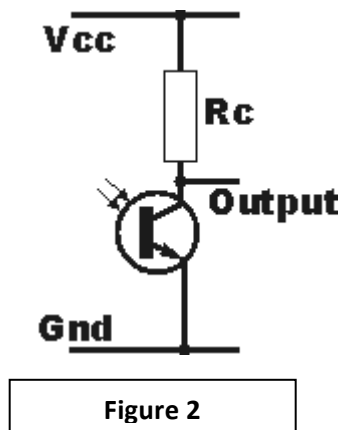

Figure 2

Phototransistors are used as "eyes" for light following of light avoiding robots. When phototransistors are installed on a robot with overlapping field of vision, they can be used to detect light and send a voltage output to motors controlling wheels. Depending on the phototransistor, the light from the laser may need to be modulated so it does not outshine all ambient light. Robots who utilize this technology are readily available and reasonable priced.

Parallax makes a commercially available robot called the Scribbler (Figure 3) with light seeking or light avoidance technology. The Scribbler has three photo resistor light sensors mounted on the front of the robot that detect light or the absence of light. The scribbler can be

reprogrammed using the BASIC Stamp® 2 microcontroller. Guiding the robot would be accomplished by shining the laser into the light sensors and essentially pushing or pulling the robot toward or away from the light. It would also be possible to program this robot to follow a laser dot shining on a flat surface above it, like a ceiling. To make this possible the display height would need to be very small and the motion of the robot would be limited. This would also be difficult to control using an indirect method of controlling the movement of the laser. The height of the display case would need to be short enough so the robot can sense the light on the roof, which would leave a limited amount of space to place the reflectance material.

Figure 3: Scribbler

Parallax also makes a commercially available robot called the Boe-Bot that will track light shining directly in front of it. The Boe-Bot is programmed using the same the BASIC Stamp® 2 microcontroller as the Scribbler. By writing programs in PBASIC we would be able to build a sensor circuit and program the robot to move on its own. The robot would be programmed to follow the path of laser light. The operator would shine the laser light directly on the ground in front of the robot and guide the path of Curiosity. This method would give the robot a large range of movement and the path taken by the robot would be easy to see by the students. Figure 4 shows the Parallax Boe-Bot.
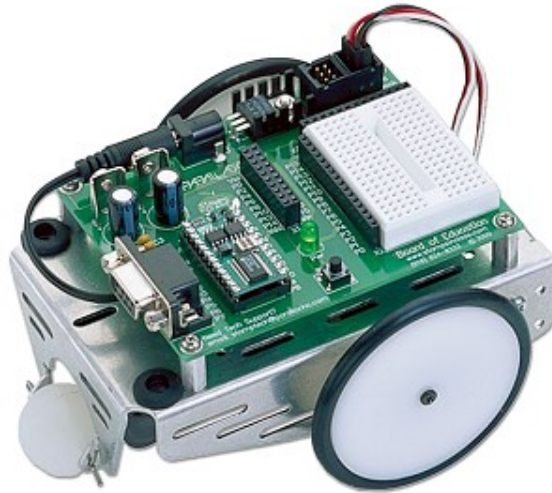
Figure 4: Boe-Bot

This design would be applicable to both direct and indirect methods of controlling the movement of the laser light. If an indirect method of laser movement were chosen, the laser could be mounted in a stationary position and shine at a "satellite". The satellite would be made with the piezoelectric material and the operator would control movement. The satellite would be covered with some type of reflective material so the light would then be reflected on the ground in front of the robot.

Another way of guiding the path of the robot would be with the use of a wireless webcam. With a webcam mounted on top of the robot, the robot would be able to follow the movement of the laser dot on the ground. The webcam will be wireless and send a signal to a computer program that would guide the robot to follow the laser dot. This would be a more complex method of controlling the robot than the light sensor eye method, as it would call for reprogramming of an already existing robot.

Another method to control the movement of the robot would be to point the laser at a remote, which would then signal the robot to move in specific directions. The remote would have an array of light sensors each actuating a movement in a specific direction (right, left, forward, backward). Optical sensors can convert light to frequency or light to voltage. The array would work the same as the light sensor eyes in that it would convert the light to a voltage, which would be controlling the power to the robot. The operator would shine the laser at a sensor and

move the robot in one direction. When the laser is shined at a different sensor it would signal movement in a different direction. The remote would be wirelessly connected to the robot and the robot would be programmed to move in 4 certain directions. This design allows for direct or indirect control of the laser movement. The light sensor array could also be placed on top of the robot but this would make for more difficulty in aiming the laser light if the robot moves a large distance.

2.2 Concept 2: Satellite Transmission Game

Some satellites, like those from Cedrat Technologies, utilize piezoelectric smart material for micropositioning and vibration damping. The advantage to utilizing piezoelectric materials to produce movement is their ability to be controlled accurately, all the way down to the nano scale. Drawing from this idea of using the material to position parts of a satellite, this game was designed.

After collecting data, satellites need a way to send the data back to researchers and scientists on earth. This can be done by either a high or low gain antenna. The high gain antenna is used for sending a lot of data very quickly, while the low gain antenna transmits more slowly. However, the high gain antenna requires precise positioning to send data effectively, while the low gain does not. This game mimics positioning the high gain antenna on the satellite to effectively transmit "data" back to different earth based satellite dishes. The laser beam in the exhibit represents the data.

There will be 5-10 mock miniature satellite dishes positioned downstream from the user controlled laser beam. Each miniature satellite will be equipped with an LED light and a phototransistor. The LED's and phototransistor from each miniature mock satellite dish will be wired to and controlled by a microcontroller. When an LED lights up on the satellite dish, the user's goal is to position the laser beam via joystick onto the corresponding phototransistor. After this is complete, the LED light goes out on that satellite dish and lights up on another. The user must position the laser again onto the corresponding phototransistor. This process continues until all of the "data" has been sent to the various satellite dishes. In order to include a competitive aspect to the game, it will either be equipped with a scoring system or a timed component.

An advantage to this design concept is that its use should be fairly intuitive, even for school aged children. This style of game is similar to the "point and shoot" type arcade games which most people are already familiar with. The competitive aspect of the game will also help to make it enjoyable, as most people enjoy a challenging game rather than one with no quantifiable result. Also, this game can be easily scaled up or down based upon how much room the Challenger Learning Center would like to use.

2.3 Concept 3: Laser Activated Satellite Control

This design is based on the real life application use of smart material in satellites in space. Piezoceramics are currently used in adjustable antennas for satellite communications. An antenna with piezoceramic components is able to bend slightly when provided with voltage. The piezoceramics can change the reflector shape and this allows for an improvement of signal quality while the satellite is in orbit. This real life application was what provoked our third design concept.
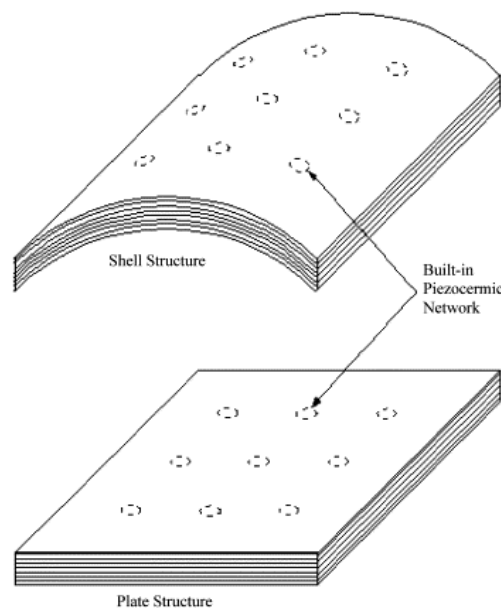

Figure 5: Example of how an outer reflector embedded with piezoceramics can be bent.

The exhibit is set in a rectangular clear case. All the components are placed inside the case. A laser is fixed from one end of the small exhibit and continuously turned on from the moment the exhibit is in use. A piezoceramic is placed at the top of the case and is wrapped in a reflective material or a mirror. The laser is to hit the piezoceramic and reflect it towards the bottom of the case where four photodiodes will lie. These photodiodes are very vital, as the student will be challenged to shine the light on each one respectively. He or she will do so by adjusting the voltage on the piezoceramic. Depending on the voltage given, the piezoceramic

will bend accordingly and the laser will have a range of possible movement at the bottom of the case where the photodiodes are located.

There will also be a model "satellite" at the bottom of the case right near the photodiodes. The inside of the satellite dish will also be covered with reflective tape. Shining the laser on each individual photodiode will initiate a response. The photodiodes will be programmed to induce movement on the satellite. For example, shining the laser on one photodiode will adjust the satellite and tilt it to the left. Shining the laser on another satellite will tilt it to the right, and so on. This is possible with the attachment of a tilt kit at the bottom of the reflective satellite. The direction the satellite tilts is important because the laser will also be reflected from the photodiode onto the satellite and then from the satellite onto a map towards the back end of the clear case.
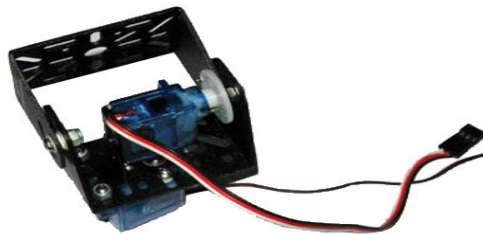

Figure 6: Pan/tilt kit to be attached to bottom of reflective

The children's challenge will be to adjust the satellite correctly, by hitting the different photodiodes, and projecting the laser beam onto the map with different countries. The student will have to try to communicate with different countries by adjusting the satellite. Though not ideal in the sense that in real life the piezoceramics are connected to the satellite, the student will get an appreciation and understanding for how smart material can affect satellite communications in space.

Figure 7: Example map with countries. Students would be challenged to shine the laser on specific countries to "communicate" with them via satellite.

Some pros are that this exhibit resembles a real life use of smart material. Piezoceramics are used directly in satellite communications in space, even if not in the same exact manner they are used in this project. Students would get a firsthand look at the advantages of such innovative material. Some disadvantages to this concept are that it is not quite a game or exciting. Students will see the results of movement through the laser but not much else. A timer could possibly be used to see how fast a student can "communicate" with all countries selected. Other than that it might seem a bit boring to school aged children.

2.4 Concept 4: Mars Curiosity Rover "Chem-Cam"

This design concept is also a bit reflective of a real world application. The car-sized rover, Curiosity, which is currently on Mars, is equipped with a special laser called Chem-Cam on its head. This laser actually fires in brief pulses at rocks on Mars. The energy from the laser excites atoms in the rocks into an ionized, glowing plasma. Curiosity is also equipped with a telescope on its head. ChemCam catches the light from that spark with a telescope and analyzes for information about what elements are in the rock.

This idea is somewhat represented in this design. The same clear case as for all designs is to be used. The laser is once again fixed towards the top at one end of the case. A reflective surface or a mirror is placed on top of the case near in visible sight of the laser. The laser is also continuously on for the duration that the exhibit is in use. With the laser on, the light beam is to hit the reflective piece or mirror at the top and project the beam downwards where a small robot is placed. This robot will be symbolizing "Curiosity" on its journey on Mars. Instead of a ChemCam attached on its head, Curiosity will be equipped with two piezoelectric ceramics. These piezoceramics will be assembled in such a specific manner where there are two degrees of freedom and will also be covered with reflective material such that the laser beam reflects off it. Its movement, as piezoceramics behave, will be subject to the amount of voltage they receive. The reflected beam will be cast onto a screen that will be modeled after Mars' surface.

That voltage given is the interactive portion of the display. The children who are using the exhibit will vary that voltage. With the piezoceramics moving, the beams reflection will vary onto "Mar's surface" which will be covered with multiple photodiodes. These photodiodes are representative of the rocks that the real Curiosity is firing at with its ChemCam laser. The goal for the children will be to project the reflected laser onto the different photodiodes or "rocks". This will be done by varying the voltage given to the piezoceramics. When each respective photodiode is hit with the laser, it will trigger a reaction. That reaction is still yet to be determined. It could include fun facts about the real Curiosity on Mars or a timer can simply be set and students will be challenged to see who hits all "rocks" the fastest.
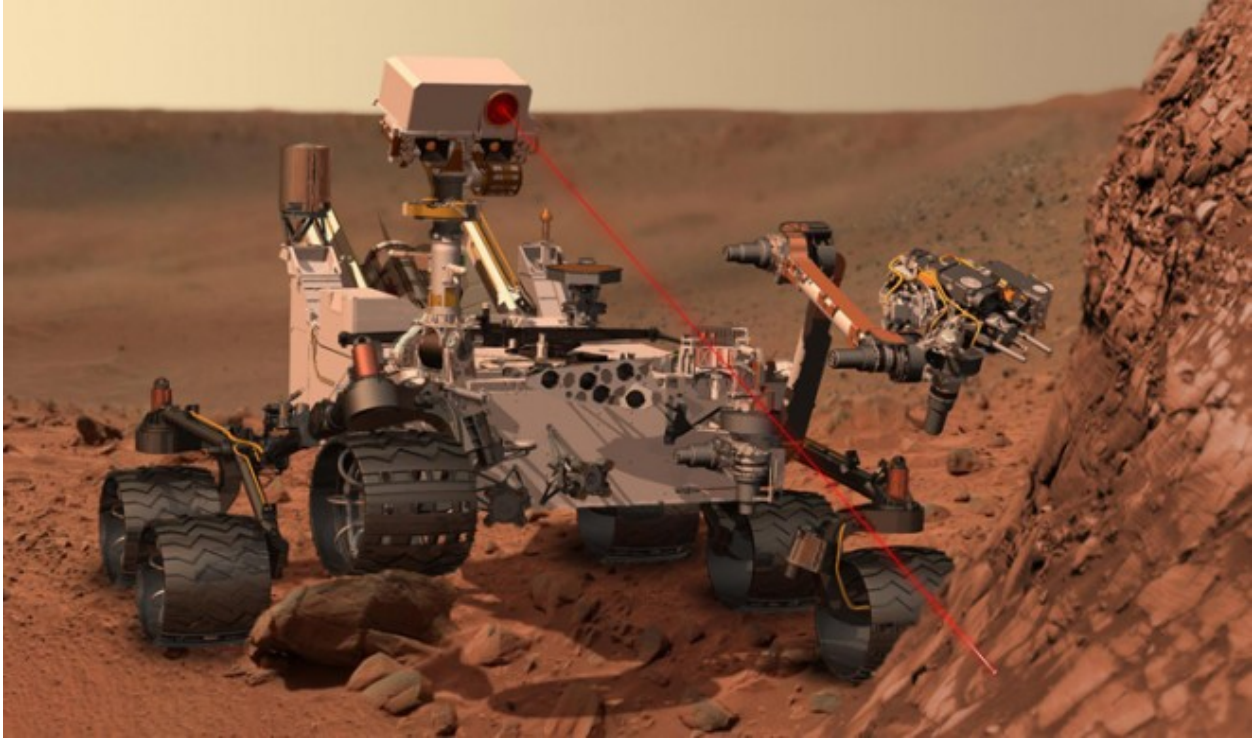
Figure 8: This is a picture of the real Curiosity. Our project would somewhat model this. Photodiodes would be placed along a wall and signify the "rocks" that Curiosity fires at.

Pros of this design include that it will inform children of current NASA events. The importance of this cannot be understated as the Challenger Learning Center aims to improve the knowledge of space to students. Another pro is that the children using the exhibit will directly see how voltage alters piezoceramics as they try to fire onto the numerous photodiodes.

2.5 Decision Matrix

Specifications	Weight	Concept 1: Laser Manipulated Robot		Concept 2: Satellite Transmission Game		Concept 3: Laser Activated Satellite Control		Concept 4: Mars Curiosity Rover Chem-cam	
		Rating	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Estimated Cost	25%	3	0.75	4	1	4	1	2	0.5
Applicability to the Learning Center's educational program	40%	3	1.2	4	1.6	5	2	3	1.2
Educational Value	20%	3	0.6	3	0.6	3	0.6	4	0.8
Entertaining	15%	4	0.6	4	0.6	4	0.6	3	0.45
Total	**100%**		**3.15**		**3.8**		**4.2**		**2.95**

Section 3: Final Design

3.1 Overview

3.2 Piezoelectric Control Module

3.3 User Interface

3.3.1 Circuits

3.3.2 Flow Diagram

3.4 Satellite

3.4.1 Light Sensor Circuit

3.4.2 Laser Power Control Circuit

3.4.2 Flow Diagram

3.5 Control Calculations

3.1 Overview

Upon pitching our design concepts to the Education Assistant/Flight Director at the Challenger Learning Center, Mr. Hawbecker, he expressed interest in our laser controlled satellite concept. He went on to explain how he would like to be able to implement it in the Learning Center's lobby, and incorporate it into their Mars flight mission. The Learning Center conducts Mars flight missions with middle school aged children, and each student is assigned a job such as pilot or scientist. Mr. Hawbecker hoped to add another job, possibly something like communications director. It could be this persons job to re-establish communication with the control center. They could simulate this by repositioning a laser on a large map of Florida, located in the Challenger Learning Center lobby. Our final design utilizes this need for a communications director, so that the Challenger Learning Center can have not only a museum exhibit, but something they can incorporate in their flight to Mars as well. Next, each facet of the detailed design will be displayed and detailed.
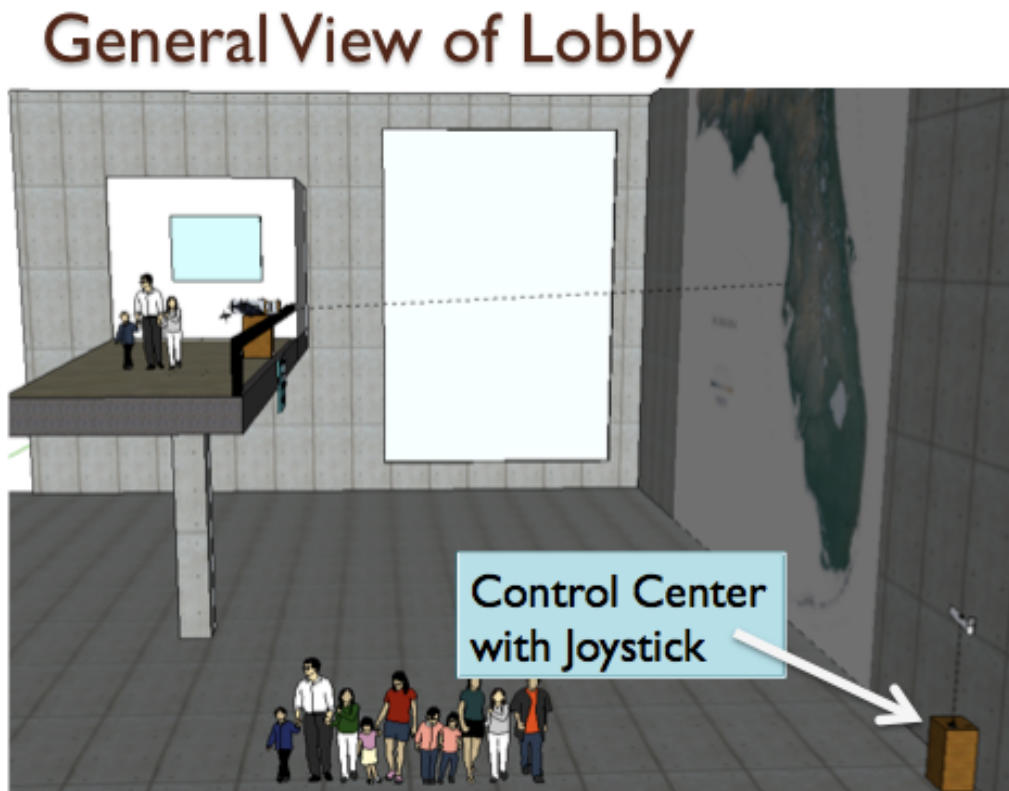

Figure 9: General View of Challenger Learning Center Lobby

Depicted above is the Challenger Learning Center lobby. Located across from an approximately 50 ft x 50 ft map of Florida is a balcony walkway. In the bottom right of the image, the first piece of our design is shown. This control center with joystick will house two amplifiers, two MFC's, a laser, a microcontroller, a joystick, and a power supply. It will be built out of wood, and the piezoelectric material and lasers will be enclosed on four sides with an acrylic casing. The students would be able to see the laser and the movement of the piezoelectric material, but would not be able to touch any components except for the joystick. The microcontroller will receive input from the joystick, and it will output a signal to the amplifiers which will power the piezoelectric material. The microcontroller will also control the power provided to the laser. Upon moving the joystick, the microcontroller will turn a laser on. If the microcontroller receives no input after a specified amount of time, the laser will turn off in order to conserve life.
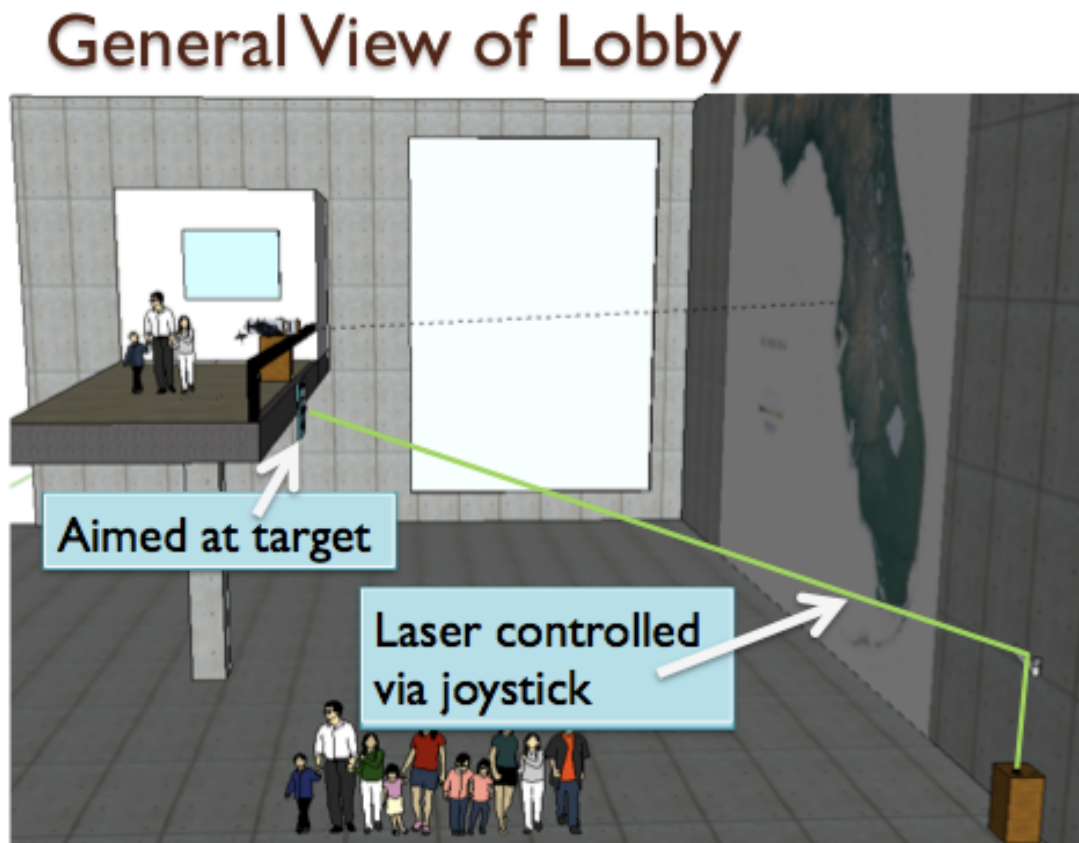

Figure 10: General View of Lobby, Phase 2

Now, the joystick has been moved and the laser has been turned on. This laser is directed straight up, and then hits a mirror, before being directed across the room at a target hanging from the balcony. The reason the mirror was included, rather than simply directing the beam straight across the room from the control center, was to direct the laser beam out of any person's line of sight.

Lasers can be potentially damaging to one's vision, and eye contact is not recommended. A low powered laser, one that is deemed okay for intermittent eye contact, will be used, but one can never be too safe. Also, if the mirror was not utilized, anyone standing in the path of the beam would block it from reaching the target, rendering the exhibit useless. With the mirror positioned at a height of approximately seven feet, these potential problems can easily be avoided.

The aiming of the laser is made possible through the controlled bending of the piezoelectric material. The more the material bends, the more the laser is moved. The amount of bending is regulated via voltage, which will be provided by amplifiers. The amplifiers will be controlled via a microcontroller, which receives input from the user via the joystick.
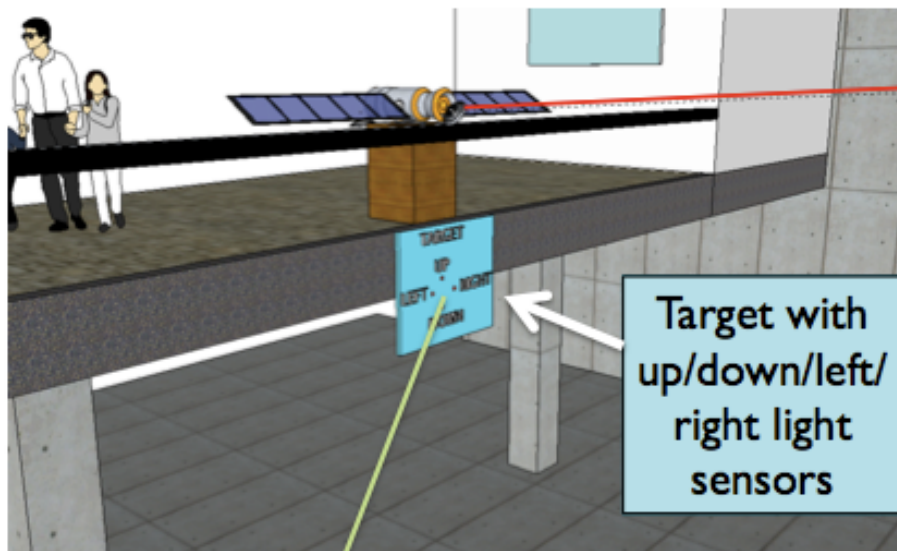

Figure 11: Challenger Learning Center Lobby, Balcony View

Here, we see a better view of the balcony with the hanging target. We can see the green laser aimed at it, which originated from the control center. The target will contain four light sensors. Each light sensor will be wired to a second microcontroller mounted on the balcony. There will be one light sensor each for up, down, left, and right movement. When a laser beam is directed at a light sensor, the resistance of the sensor changes. This signal will travel from the light sensor to a second microcontroller located on the second level.
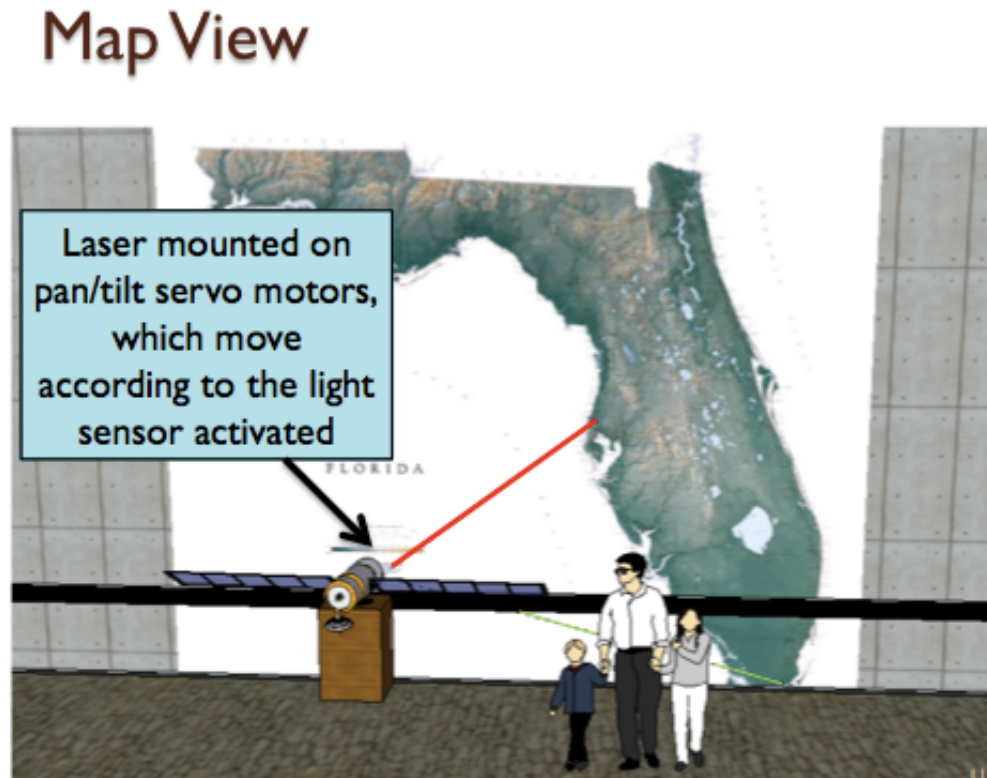

Figure 12: Challenger Learning Center, Map View

Displayed above in Figure 12 is the view from the balcony walkway. Shown is a mock satellite, which is for display purposes only. On the satellite, a pan and tilt servo motor combination will be mounted. This pan and tilt kit will be controlled via the second microcontroller on the balcony. Upon receiving a signal from the light sensor, the microcontroller will move the pan and tilt kit accordingly. On top of this pan and tilt kit will be mounted a second laser. This laser will project across the room onto the map of Florida. It is this laser that symbolizes the communication link from satellite to Earth. Depending on the needs of the flight to Mars simulation, the students may need to move the laser to Tallahassee, or another city in order to re-establish communication.
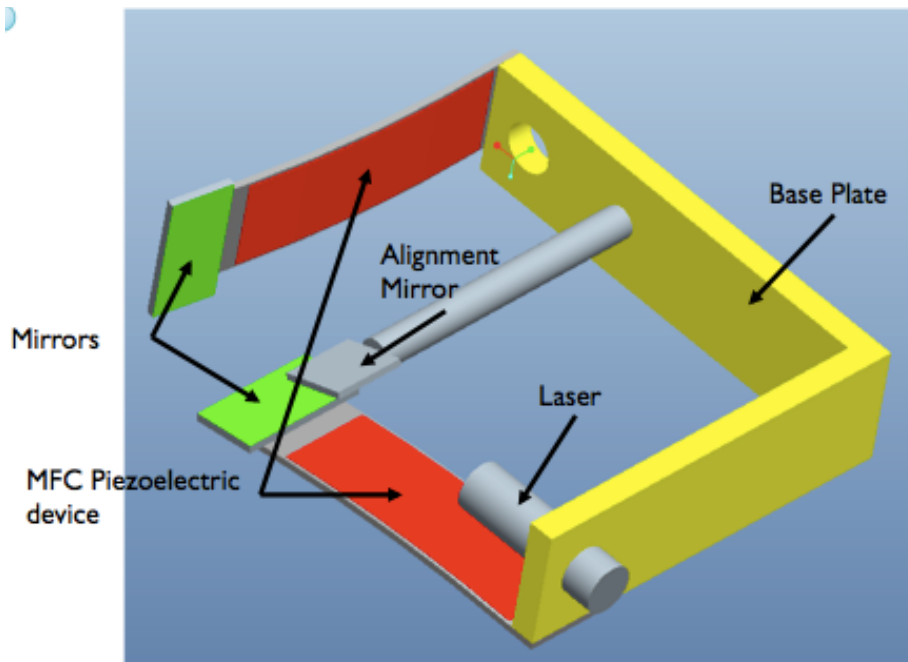
3.2 Piezoelectric Control Module

Figure 13: Piezoelectric Control Module, General View

Figure 13 depicts the theoretical positioning of the piezoelectric laser control module. The baseplate, shown in yellow, would secure the alignment mirror, the laser, and the two MFC's. Each MFC would have a small mirror mounted on the end of it, in order to reflect the laser. The purpose of the alignment mirror is for packaging purposes. In order to keep all components mounted in close to the same plane and to simplify machining, the alignment mirror was added. The alignment mirror redirects the laser, so the angle of incident for the first MFC is 45 degrees.
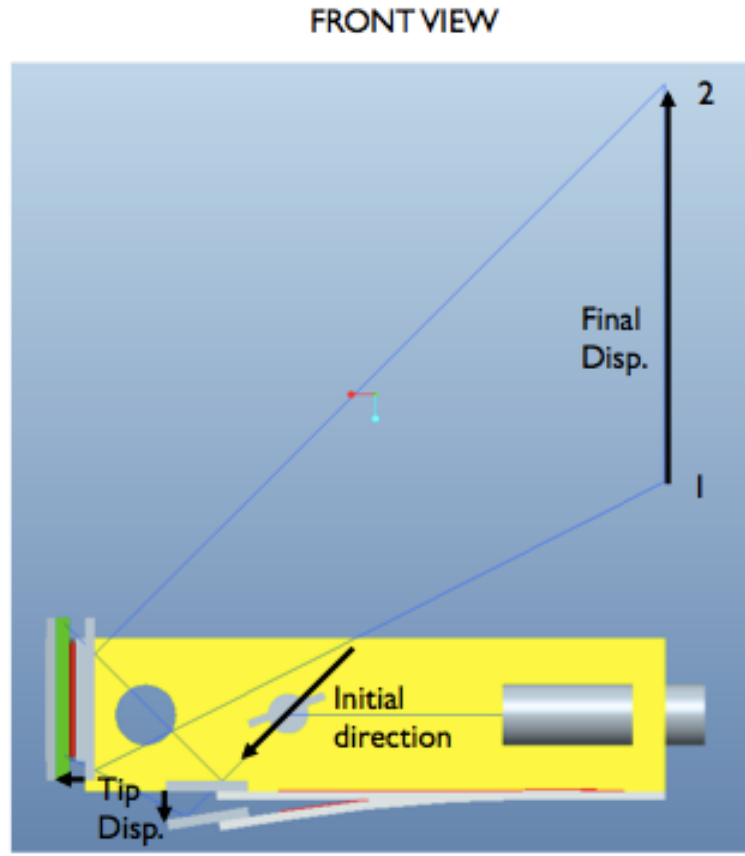
FRONT VIEW

Figure 14: Piezoelectric Control Module, Front View

Figure 14 depicts the front view of the piezoelectric control module. One can see the first MFC with no voltage applied, and then with the maximum of 1500V applied. The no voltage a max voltage conditions are shown in order to show the range of output from the laser. Point 1 on the figure shows the final laser position when the MFC is supplied with 1500V. Point 2 on the figure shows the final laser position with no voltage applied. The final displacement depends upon the distance from the module to the target.
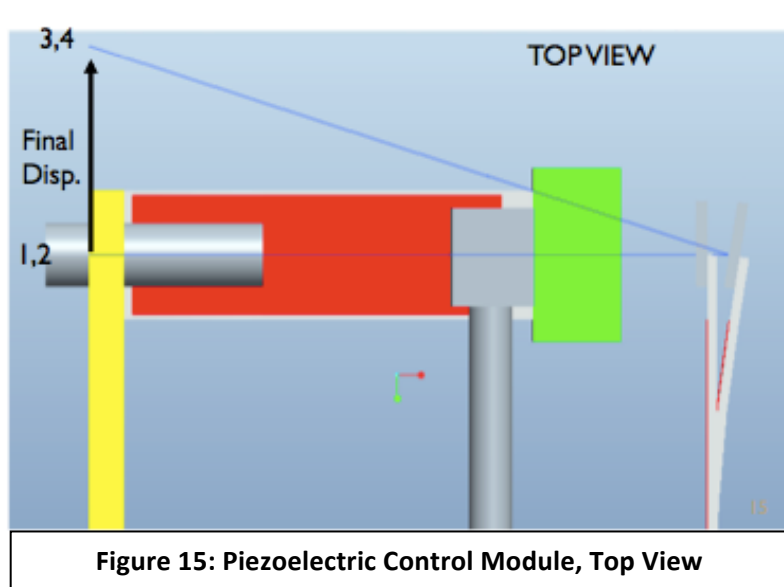
Figure 15: Piezoelectric Control Module, Top View

Figure 15 depicts the top view of the module. The bending of the second MFC yields a second degree of freedom, as shown above. Again, this final displacement will depend upon the final distance from the module to the target.
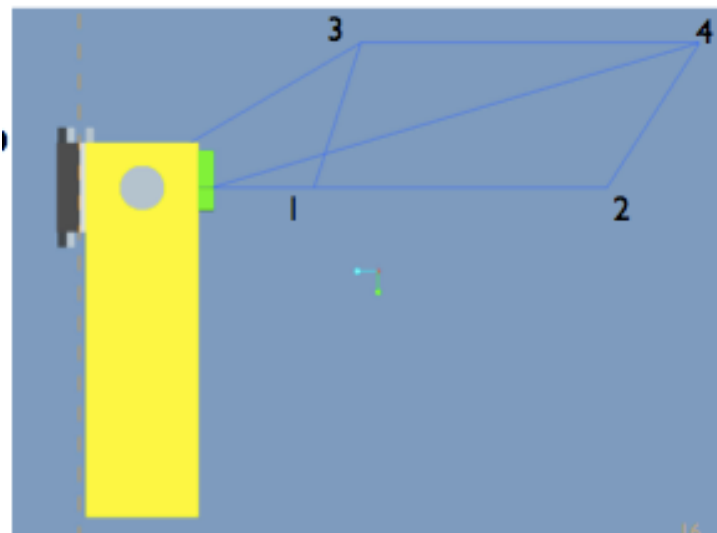

Figure 16: Piezoelectric Control Module, Front View

As shown in Figure 16 above, the final area that the laser can be displayed on is a quadrilateral. This differs from the expected square or rectangular area that was initially expected. Upon further examination however, the reflections from the various geometries and tip displacements result in this unique shape.

3.3 User Interface

3.3.1 User Interface Circuits

For the user interface, there are two choices for the joystick; an eight way tactile switch or two analog potentiometers. Both options will be discussed, starting with the two potentiometer option. A potentiometer converts position proportionally into resistance. Through the use of an op amp, such as the LM 358, a constant current source can be created to produce a linear position to voltage relationship.
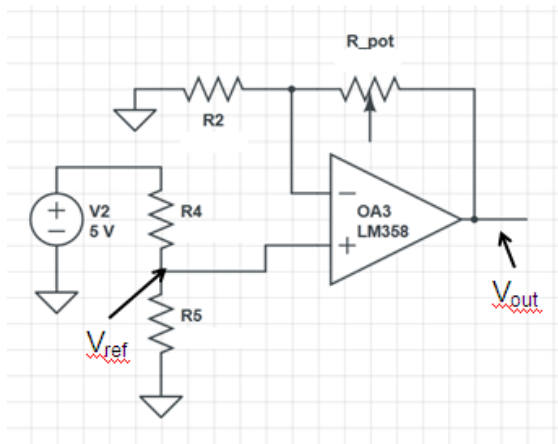

$$i_{R2} = \frac{V_{ref} - 0}{R_2}$$

$$V_{ref} = V_2 * \frac{(R_5)}{(R_4 + R_5)}$$

$$V_{out} = i_{R2} * R_{pot}$$

Figure 17: Circuit, User Interface

However the LM 358 chip limits V_{out} from 0 to $V_{power} - 1.5$, so if it is powered with 5 volts then the output is limited from 0 to 3.5 volts. So using the maximum resistance of the potentiometer, i_{R2} is set so that:

$$i_{R2} = \frac{V_{ref} - 0}{R_2} = \frac{V_{power} - 1.5}{R_{pot,max}} = \frac{3.5}{R_{pot,max}}$$

This produces a linear relationship from V_{ref} to $V_{power} - 1.5$ as R_{pot} increases. To maximize the range of V_{out}, V_{ref} should be minimized. The output voltage can then be read by the Arduino analog-to-digital convertors. This same relationship can also be utilized with a photo resistor and will be discussed in the section describing the light sensor.

The second type of joystick is a multidirectional switch. This only requires powering the joystick and one digital pin per direction of the switch. This configuration can be used to either hard code in a set position for each direction or increment the position in the given direction. Testing will be conducted in the spring semester on controlling the piezos.

3.3.2 User Interface Flow Diagram

Start

Power on exhibit

User inputs voltage
(via joystick)

Target laser switched on
by the arduino

Joystick microswitches
turn on/off

Arduino reads
microswitches

Arduino inputs signal
to amplifiers

Amplifiers power
piezoceramics

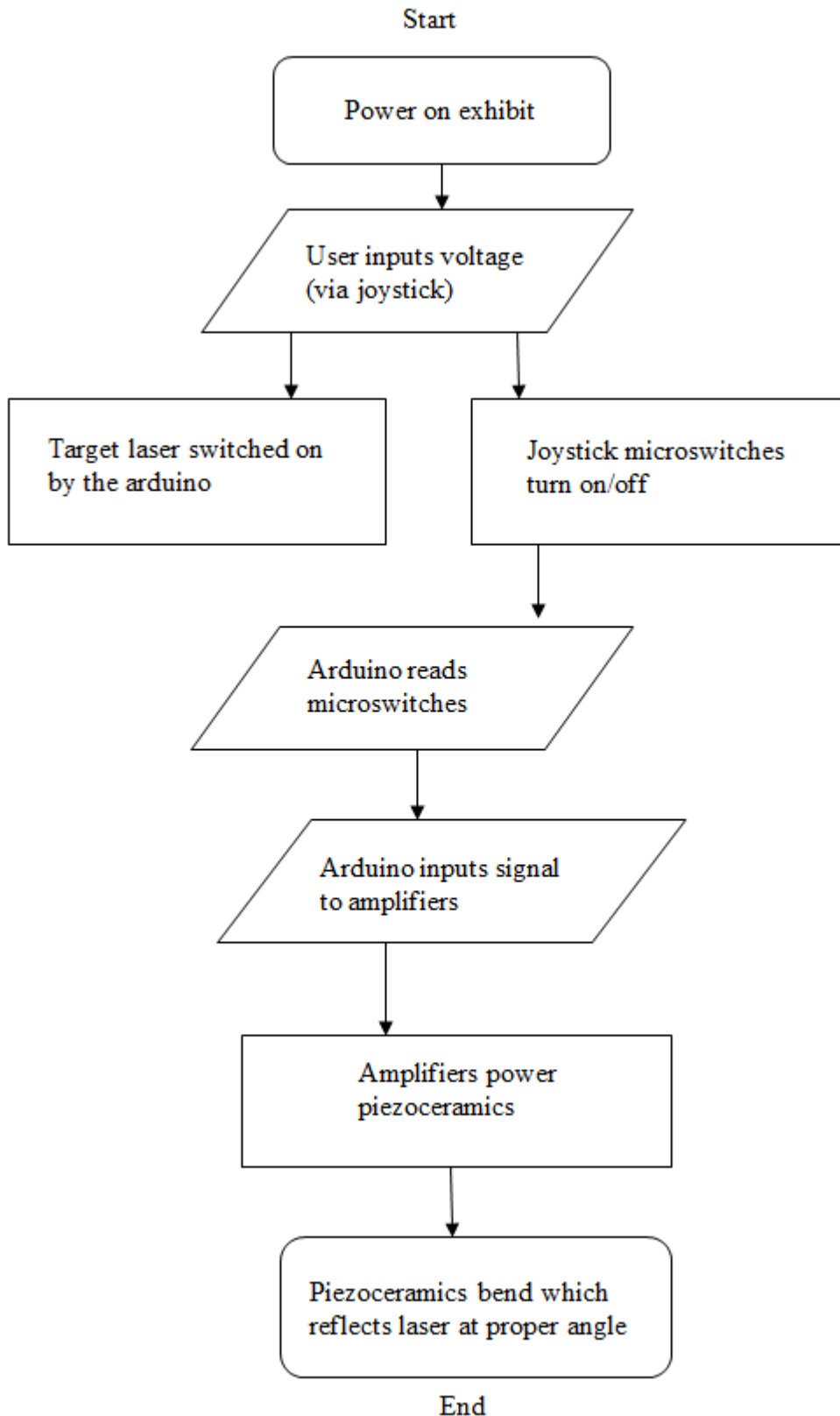Piezoceramics bend which
reflects laser at proper angle

End

Figure 18: Flow Diagram, User Interface

3.4 Satellite Station

3.4.1 Light Sensor Circuit

The same constant current source used with the potentiometer to create a linear voltage relationship can be used to create a relationship between light and voltage. As the light on the photo resistor increases, its resistance decreases, thus producing an inversely proportional relationship between light and voltage. The output voltage can then be fed into the inverting terminal of a comparator.
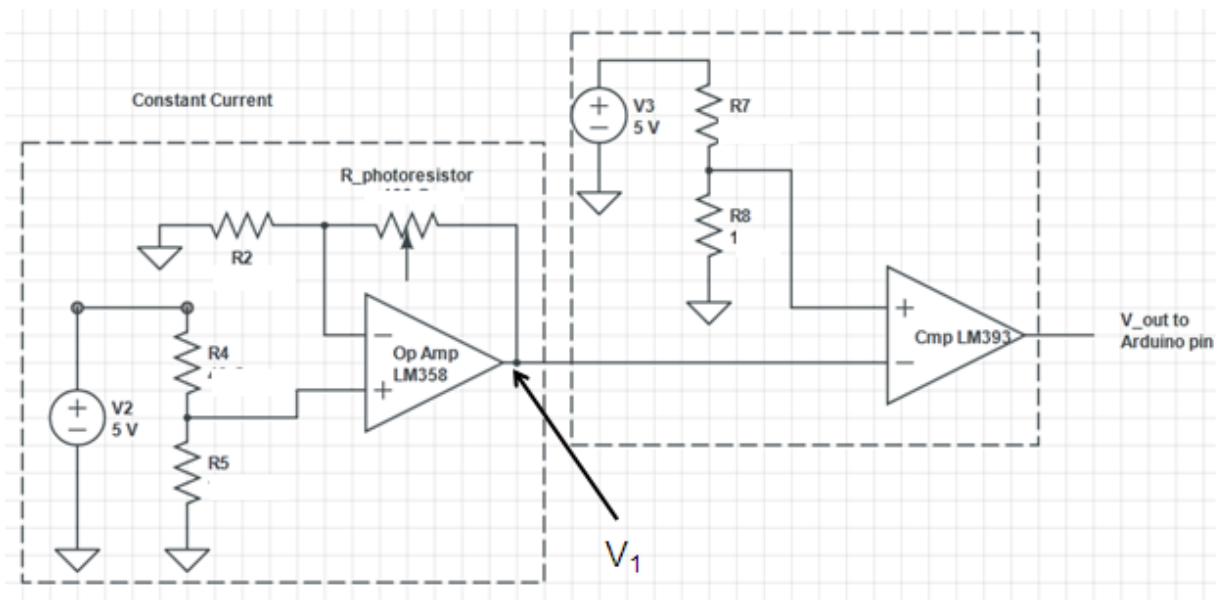

Figure 19: Light Sensor Circuit

The reference voltage being sent to the non-inverting terminal is set so that when the laser is detected (V_1= minimum), the output will be high (5 volt) and low (0 volts) when no laser is detected (V_1=max). Therefore the reference voltage should be between $V_{1,min}$ and $V_{1,max}$, basically creating an on/off switch. If there are problems with the switching some hysteresis can be added to improve when it switches. This can be used to program the servos to go to set points on the map depending on which switch was last tripped or to increment the position on the map in the desired direction. Some discussion with our sponsor and some testing will still need to be conducted to determine which will be more desirable.

3.4.2 Laser Power Control Circuit

It would be advantageous to be able to power the laser on/off via the microcontroller. This can be done very simply either through the use of a NPN transistor or, if more current is needed, a NPN Darlington array can be used in a similar fashion.
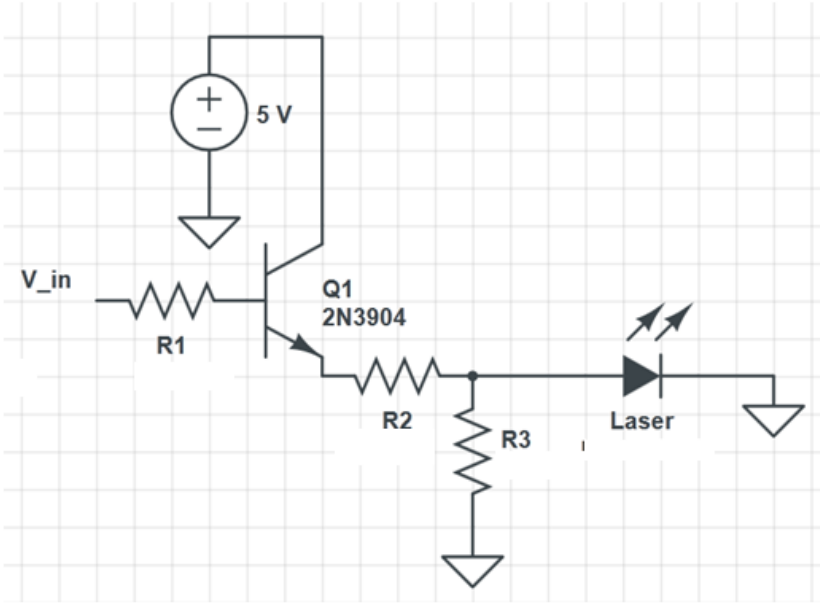

Figure 20: Laser Power Control Circuit

3.4.3 Satellite Station Flow Diagram

Start

Laser hits target
light sensors

Light sensors feed
Signal to 2nd arduino

Arduino powers pan
and tilt kit

Pan and tilt kit moves according
to which light sensors are hit
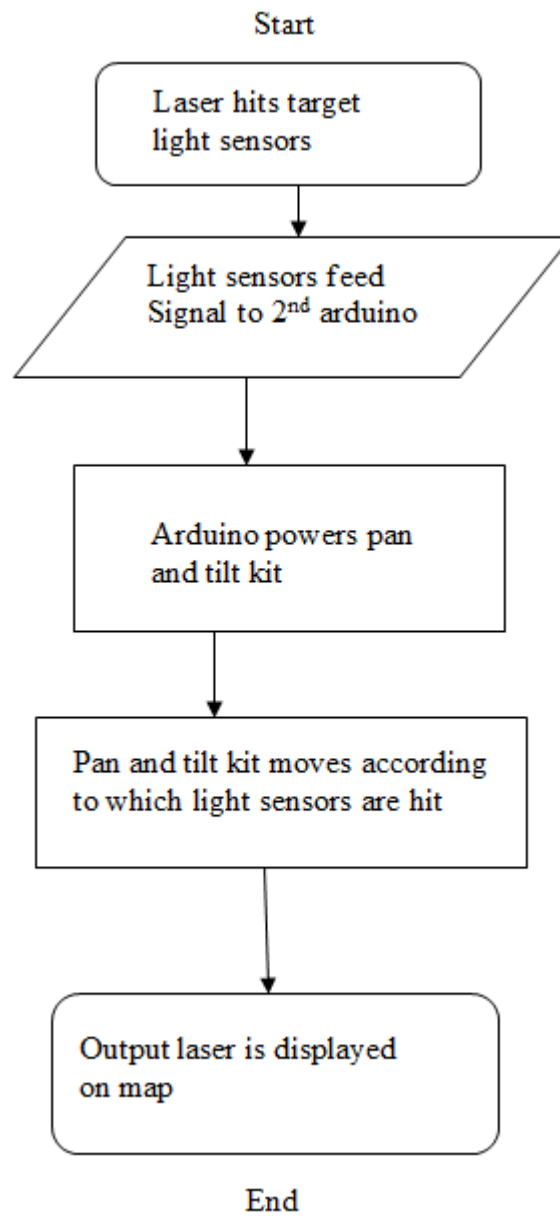
Output laser is displayed
on map

End

Figure 21: Flow Diagram, Satellite Station

3.5 Control Calculations

The piezos will need to be able to reflect the laser to hit a circular target approximately 35-40 feet away that is approximately 3-4 feet in diameter. This tells us that an output angle of approximately 5 degrees is needed. Currently our design will produce an output angle between 12-18 degrees. There are two possible solutions to limit the angle. The first being to increase the thickness of the beam, and the second would be to limit the voltage applied to piezos. In order to limit the voltage applied to the piezos either the input signal into the amplifier must be limited, but this would limit the resolution, or the other option would be to use a smaller amplifier where the whole output range could be used. This would not only limit the maximum applied voltage, but also increase the resolution allowing for a finer control. This will be decided after some testing in the lab.

Section 4: Conclusions

4.1 Future Roadblocks and Concerns

4.2 Environmental and Safety Issues and Ethics

4.3 Poster

4.4 Final Thoughts

4.1 Future Roadblocks and Concerns

Though we have yet to begin the assembly of our exhibit, we have already begun thinking ahead into the spring semester. This is when the actual construction of our project will take place. We have already brain stormed into what possible dilemmas may arise. We did so because we want to be as prepared as possible so that our exhibit can be as successful as possible.

One problem that may arise involves the light sensors. As it has been described earlier, the user will aim to hit one of the light sensors with the laser as it produces movement in the satellite. The problem might be in the user seeing those light sensors. Their size is quite small as the largest one is only about the size of a quarter. When placed across the lobby, this might be quite difficult for the user operating out exhibit to see. One proposed solution would be surrounding each respective light sensor with LEDs. These LEDs would be lit up and make them quite easy to see. Another possible solution to this could be placing a monitor with a webcam on the stand where the user is. This webcam would be aimed directly at the satellite. This would provide a magnified view of the target that the user could simply see on the monitor screen. Both of these are viable solutions and they will be looked more into if this problem does indeed arise.

Another possible problem could be students understanding our project. Since it is primarily geared towards 5th to 8th graders, it may be a bit complex for them to comprehend it all. This issue can be addressed by having a poster placed on the wall next to the stand. This colorful poster would have proper step by step instructions for operation. More than using the exhibit properly, we want the students to also learn since expanding knowledge of smart materials was also part of our goal. Therefore the poster would have more than just instructions. It would also be filled with information about smart material and fun facts.

4.2 Environmental and Safety Issues and Ethics

The importance of safety cannot be understated as it is our number one concern. We want to ensure all users of our exhibit can access it and operate it safely without any chance of injury or harm. Since our exhibit involves the reflection of lasers across a lobby, certain precautions were taken to make sure no one's eyes come in direct contact with the laser. This was done by placing a mirror eight feet above form where the user's stand will be. After the user applied voltage and the laser hits the piezoceramics, it will be reflected straight up onto the mirror placed eight feet above. It is after this that it will be reflected across the lobby and onto the satellite on the 2nd floor balcony. This mirror forces the beam to already be at 8 feet high when crossing the lobby so it will be well above anyone's head and eyes.

As seen in our description of our design, a lot of electrical components are at play in our exhibit. Hence, a lot of electrical wiring will be needed. All this electrical wiring can be a potential electrical hazard. To prevent any possible incidents from arising, all electrical wiring will be enclosed in a locked case. This case will be accessible only by specified personnel and to be kept away from the users or student.

Environmental safety and hazards is also always an important aspect to consider especially in this day in age where we are trying to be as green as possible. In this case, no environmental hazards exist as no waste is produced with our design. There is also no real interaction with the outside environment as the whole operation takes place indoors in the lobby. Our project is very environmental friendly.

As we have learned throughout our schooling at the college of engineering, engineering ethics is an important code that must be followed. We know we have a set of standards to live up to as engineers and safety for the public should be number one. We know to conduct ourselves in a professional matter and perform services only in our competence. We took pride in upholding the integrity of the engineering profession in our communication with our sponsors and advisors. Enough cannot be said about the moral principles that apply to the engineering practice and we shall all continue to maintain them as we progress in our engineering careers.
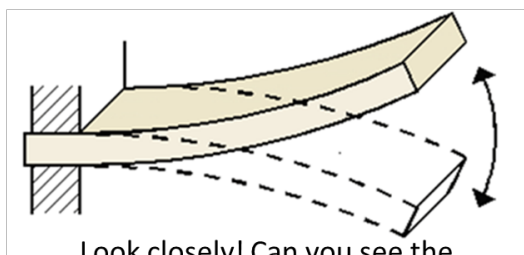
4.3 Poster Design

A poster will be placed next to the user interface that includes the directions for operation and a description of the science behind smart materials.

Figure 22: Poster Design Concept

4.4 Final Thoughts

The final output from this project will be a ready-to-use interactive museum display that will be installed in the lobby of the Challenger Learning Center in Tallahassee, FL. Using a joystick, arduino, and two amplifiers, the operator will be able to control the movement of two macro fiber composite piezoelectric ceramics to generate two degrees of freedom of laser light movement. The laser light will represent communication from outer space to difference locations in Florida.

Testing of the joystick control will begin in the upcoming spring semester. We will test the control using MFCs and amplifiers provided by Dr. William Oates. The guidance of the laser light beam using the analog joystick needs to be verified. The light sensor control of the pan and tilt kit combined with the projection of the second laser's light beam on the map will also be tested and the final decisions on the overall design will be made. Once the control of the MFCs is verified the final purchasing of materials will take place. Prototype building will begin once the materials arrive and installation into the Challenger Learning Center will take place soon after.

Section 5: References and Appendices

5.1 References

5.2 Appendices

5.2.1 Schedule

5.2.2 Bill of Materials

5.2.3 MATLAB Codes

5.1 References

"'NASA Invention of the Year' Controls Noise and Vibration." *NASA Spinoff*. NASA.gov, n.d. Web. 05 Dec. 2012. http://spinoff.nasa.gov/Spinoff2007/ip_9.html.

"Performance High Voltage Power Supply Manufacturer." *EMCO High Voltage Power Supply Manufacturer*. N.p., n.d. Web. 25 Oct. 2012. <http://www.emcohighvoltage.com/>.

"ArduinoBoardUno." *Arduino.cc*. N.p., n.d. Web. 05 Dec. 2012. <http://www.arduino.cc/en/Main/arduinoBoardUno>.

"MFC." *Macrofiber Composite*. Smart Material, n.d. Web. 17 Nov. 2012. <http://www.smart-material.com/MFC-product-main.html>.

"Piezo Actuators to Enable High-resolution Cosmic Dust Analysis." *SME Achievements*. European Space Agency, n.d. Web. 22 Oct. 2012. <http://www.esa.int/SPECIALS/SME_Achievements/SEMAADO7BTE_0.html>.
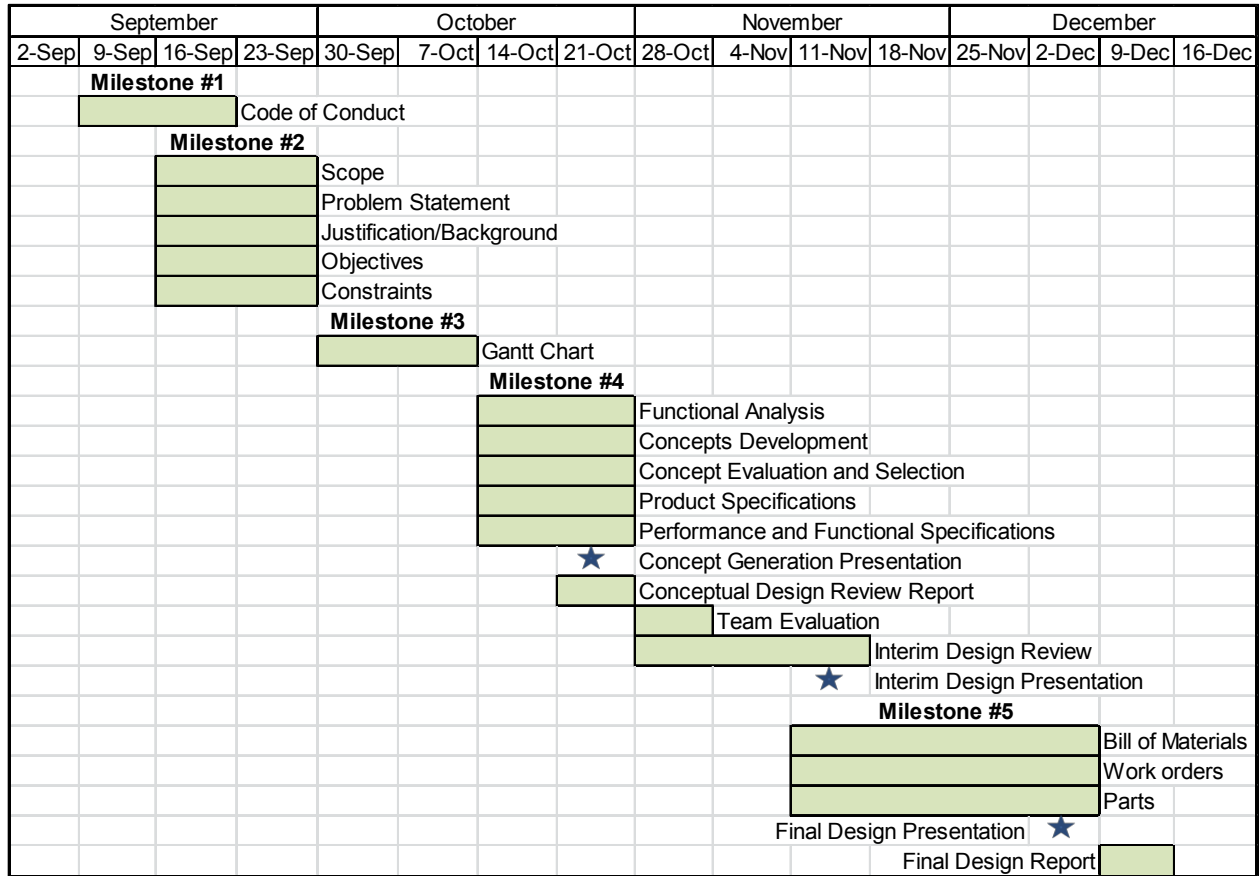
"From the Satellite to the Ground." *Imagine the Universe*. NASA, n.d. Web. 22 Oct. 2012. <http://imagine.gsfc.nasa.gov/docs/sats_n_data/sat_to_grnd.html>.

Turner, Janelle. "'NASA Invention of the Year' Controls Noise and Vibration." *'NASA Invention of the Year' Controls Noise and Vibration*. N.p., 1 May 2011. Web. 06 Dec. 2012.
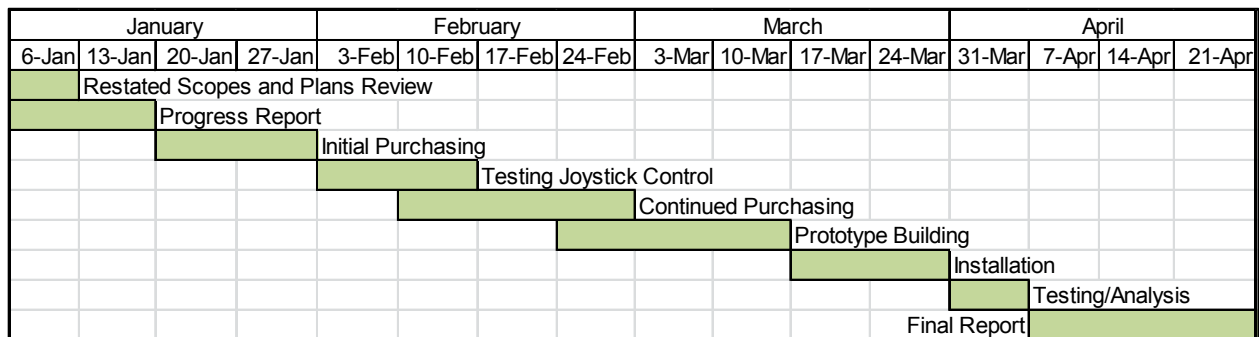
5.2 Appendices

5.2.1 Appendix 1: Schedule

Fall 2012 Semester

	September				October				November				December		
	2-Sep	9-Sep	16-Sep	23-Sep	30-Sep	7-Oct	14-Oct	21-Oct	28-Oct	4-Nov	11-Nov	18-Nov	25-Nov	2-Dec	9-Dec	16-Dec

Milestone #1
Code of Conduct

Milestone #2
Scope
Problem Statement
Justification/Background
Objectives
Constraints

Milestone #3
Gantt Chart

Milestone #4
Functional Analysis
Concepts Development
Concept Evaluation and Selection
Product Specifications
Performance and Functional Specifications
★ Concept Generation Presentation
Conceptual Design Review Report
Team Evaluation
Interim Design Review
★ Interim Design Presentation

Milestone #5
Bill of Materials
Work orders
Parts
Final Design Presentation ★
Final Design Report

Spring 2013 Semester

	January				February				March				April		
	6-Jan	13-Jan	20-Jan	27-Jan	3-Feb	10-Feb	17-Feb	24-Feb	3-Mar	10-Mar	17-Mar	24-Mar	31-Mar	7-Apr	14-Apr	21-Apr

Restated Scopes and Plans Review
Progress Report
Initial Purchasing
Testing Joystick Control
Continued Purchasing
Prototype Building
Installation
Testing/Analysis
Final Report

Section 5: References and Appendices

5.2.2 Appendix 2: Bill of Materials

ITEM	DESCRIPTION	QUANTITY	COST
Piezoelectric Material	Smart Material Corp M8528 P1	2	Provided by FSU-FAMU COE
Laser	5 mW Green	2	$30.00
Laser/Piezo Stand and baseplate	Machined Aluminum	1	$50.00
Microcontroller	Arduino Uno	2	$59.90
Amplifier	EMCO-C30	2	Provided by FSU-FAMU COE
Mirror	Wall-mountable	1	$29.46
Joystick	Arcade Joystick- Short Handle	1	$14.95
Exhibit Case	Acrylic	1	Provided by Sponsor
Exhibit Stand	Wood	1	$50.00
Pan/Tilt Kit	ROB-10335	1	$5.95
Small Servo Motor	ROB-09065	2	$17.90
Target	Craft Materials	1	$10.00
Mock Satellite	Craft Materials	1	$25
Photocell (.43" thick)	Jameco Part no. 120299	4	$7.16
Op Amp (LM358)	Jameco Part no. 120862	2	$0.50
Miscellaneous resistors			$0.00
Comparator (LM393)	Jameco Part no. 24281	2	$0.50

Total Cost: $301.32

5.2.3 Appendix 2: MATLAB Code

```matlab
clear
clear
clc
syms s11 s12 s13 s22 s33 s55 s66 s44
syms c11 c12 c13 c22 c23 c33 c44 c55 c66

% material properties for PZT
E1PZT=30.336e9; %Pa
E2PZT=15.857e9;
G12PZT=5.515e9;
nu12PZT=0.31;
nu21PZT=.16;
d33=400e-12;
d31=-210e-12;%-3.1e-10;

%thermal expansion
alpha1PZT=0e-6;
alpha2PZT=0e-6;

%%%%%%%%%%%%%%%%%%%%%%%%MATERIAL PROPERTIES%%%%%%%%%%%%%%%%%%%%%%%%%
%stainless steel 304 alloy

E1=62e9;   % Elastic Modulus
E2=E1;
nu12=0.27;   % Poisson number
G12=E1/(2*(1+nu12));
nu21=nu12;
alpha1=0e-6;   % Thermal Expansion
alpha2=0e-6;

%%%%BEAM TICKNESS%%%%%
Tmetal=.003   %meters
%%%%%%%%%%%%%%%%%%%%%%%


Tpzt=.0003;    % Thickness of PZT
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%define laminate material coefficients, A B D
%plane stress coefficients
QPZT=[E1PZT/(1-nu12PZT*nu21PZT) nu12PZT*E2PZT/(1-nu12PZT*nu21PZT) 0
    nu12PZT*E2PZT/(1-nu12PZT*nu21PZT) E2PZT/(1-nu12PZT*nu21PZT) 0
    0 0 G12PZT];

Q0=[E1/(1-nu12*nu21) nu12*E2/(1-nu12*nu21) 0
    nu12*E2/(1-nu12*nu21) E2/(1-nu12*nu21) 0
    0 0 G12];

% Neutral Axis Calculation
z2=(Tmetal+Tpzt)/2;
z1=-(z2)+Tpzt;
z0=-(z2);
```

```matlab
A= Q0*(z2-z1)+QPZT*(z1-z0);
B= 1/2*(Q0*(z2^2-z1^2)+QPZT*(z1^2-z0^2));
D= 1/3*(Q0*(z2^3-z1^3)+QPZT*(z1^3-z0^3));
F=[A B
    B D];

H=inv(F);


%define loading parameters
%applied (electric) magnetic field (V/m) A/m

%%%%%%%%%%%%%%%%%%%%%%%%APPLIED VOLTAGE%%%%%%%%%%%%%%%%%%%%%%%%%%
Voltage=700
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


Elec3=Voltage/(.00005);
%applied temperature change
dT=0;
%normal forces
Nm=[0;0;0];
NE=QPZT*[d33;d31;0]*(z1-z0)*Elec3;
%plane stress
NT=(QPZT*[alpha1PZT;alpha2PZT;0]*(z1-z0)+Q0*[alpha1;alpha2;0]*(z2-z1))*dT;
N=Nm+NE+NT;
%N=[N1;N2;N6];
%moment forces
Mm=[0;0;0];
%MxE=0.5*e31p*(z3^2-z2^2)*Elec3;
%MyE=0.5*e32p*(z3^2-z2^2)*Elec3;
%plane stress
MT=0.5*(QPZT*[alpha1PZT;alpha2PZT;0]*(z1^2-z0^2)+Q0*[alpha1;alpha2;0]*(z2^2-z1^2))*dT;
ME=0.5*QPZT*[d33;d31;0]*(z1^2-z0^2)*Elec3;
M=Mm+ME+MT;


NM=[N;M];
ek=H*NM;
eox=ek(1);
eoy=ek(2);
gamma_oxy=ek(3);
rho1=1/ek(4);
rho2=1/ek(5);


%%%%%%%%%%%%%%%%%%%%%%%%%%%SIZE OF MFC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
lx=85/1000;                                  %size of PZT in m
ly=28/1000;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


%displacement based on curvature on one direction
displz=(rho1*(1-cos(lx/2/rho1)))*1e6;
%displacement based on curvature on other direction
displz2=(rho2*(1-cos(ly/2/rho2)))*1e6;
```

```matlab
rho1=-rho1;

%Lin=3.5;        %length of cantalever in inches
%L=Lin*(.0254)

%%%%%%%%%%%%%%%%%%%%%%%%%CANTELEVER LENGTH%%%%%%%%%%%%%%%%%%%%%%%%%%%%
L = 100 / 1000                                                %meters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


Theta=1/rho1*lx;

difA=.5*(1/rho1)*lx^2;   %difflection up to end of PZT
difB=(L-lx)*sin(Theta);  %displacement caused  by angle


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%RESULTS%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Theta2=Theta*180/3.14
D_proj = 50 * sin(Theta)    %%feet
D_mirror = 6 * sin(Theta)   %%inches
difT=(difA+difB)*1000;      %%displacement of tip in mm


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```