Concept Generation

EML 4551C – Senior Design – Fall 2012 Deliverable

Team 13: Smart Materials Museum Exhibit Design

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Introduction

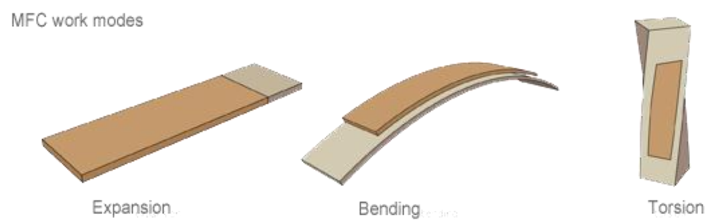
The objective of this design project is to design a construct a smart material museum exhibit. The project is headed by Dr. Oates of the FAMU-FSU College of Engineering and Ms. Susan Borland of the Challenger Learning Center. Smart materials are used in military, commercial, medical, and other research fields. They have many uses, and yet a majority of the public has little knowledge about these materials. In order to increase public awareness and knowledge about this growing field, this design project was commissioned. The museum exhibit should be simple enough for children to use, while still informing museum guests about how smart materials work and their applications. Many different types of smart materials exist, however this design will focus on the demonstration of the piezoelectric type. The museum exhibit will not only demonstrate the use of the smart material, but also be interactive in order to capture the attention of school-aged children.

All concepts presented in the report utilize a laser light controlled by the movement of piezoelectric smart material. The different methods of controlling the laser by manipulating the smart material will be discussed, and subsequently the various design concepts will be described and detailed. Finally, a comparison between design concepts will be selected using specific criteria and the highest scoring design will be selected for the exhibit.

Existing Technology

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 company by the name of Smart Material Corp. manufactures a piezoelectric actuator/sensor named Macro Fiber Composite (MFC). The MFC consists of rectangular piezo ceramic rods sandwiched between layers of adhesive, electrodes and polyimide film. It is available as either an elongator (type P1) or a contractor (type P2, P3) and each can be used to produce translation, bending, or torsion depending on how it is attached to the base material.



Overview of Typical Properties:

Max. blocking Force	28N to 1kN depending on width of MFC
Max. operating Voltage	P,S,F1: -500 to +1500V P2, P3: -60V to 360V
Max. operating Frequency	Actuator: 10kHz Sensor,Harvester:<3MHz
Typical lifetime	Actuator: 10E+8 cycles Sensor: 10E+11 cyles Harvester:10E+10 cycles
Typical thickness	300µm, 12mil

Typical capacitance	P,S,F1: 2nF to 12nF P2, P3: 25nF to 200nF

Amplifiers

An amplifier is used to increase the power of signal without otherwise altering it through the use of another power source. The amplifier needs to be able to supply the Piezoelectric with the appropriate voltage and current based on its power rating. It was suggested for us to look into an amplifier manufacturer EMCO High Voltage Company produces a line, "C series," of small regulated compact 1-watt amplifiers. As the amplifiers' output voltage increases, it does so at the expense of current. Fortunately most piezoelectric devices are voltage driven, requiring high voltage and low current. The "C series" main features are the following:

- Regulated
- Miniature Size
- 0 to 100% programmable output
- Wide input Voltage Range, 11.5 – 16VDC
- External gain adjust for calibration

PRODUCT SELECTION TABLE

MODEL	OUTPUT VOLTAGE	MAXIMUM OUTPUT CURRENT*1
C01	0 to 100 V	0 to 10 mA
C02	0 to 200 V	0 to 5 mA
C03	0 to 300 V	0 to 3.3 mA
C05	0 to 500 V	0 to 2 mA
C06	0 to 600 V	0 to 1.67 mA
C10	0 to 1,000 V	0 to 1 mA
C12	0 to 1,250 V	0 to 1 mA
C15	0 to 1,500 V	0 to 0.67 mA
C20	0 to 2,000V	0 to 0.5 mA
C25	0 to 2,500 V	0 to 0.4 mA
C30	0 to 3,000 V	0 to 0.33 mA
C40	0 to 4,000 V	0 to 0.25 mA
C50	0 to 5,000 V	0 to 0.2 mA
C60	0 to 6,000V	0 to 0.166 mA
C80	0 to 8,000V	0 to 0.125 mA

Complete List of Models on page 2

Lasers

Lasers are available in five classes: 1, 2, 3A, 3B, 4. Any Class 2 or Class 3A laser would be safe they are required to have an output beam power of less than 5 mW. Damage will only occur after prolonged exposure of more than a few seconds. All laser pointers in the U.S. are required to be either Class 2 or Class 3A and are available in a wide range of colors.

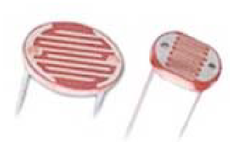
There are essentially two ways to use the piezoelectric actuators to move the laser: direct and indirect. Direct motion requires the laser to be fixed at one end with a ball joint, and two piezoelectric devices 90 degrees to each other attached to the other end allowing for 2 degrees of freedom. Indirect motion requires the use of at least one mirror and two piezoelectric devices. One mirror can be rotated on two axis 90 degrees to each other or two mirrors can be aligned and rotated on axis 90 degrees to each other with each mirror providing 1 degree of freedom. Both of the mirror systems can be bought, but they are very expensive.

Light Sensors

There are three main types of light sensors: photodiode, phototransistor, and photo-resistor. Photodiodes have a large dynamic range (850-1050nm), low cost, and fast response times, however their limiting factor is their output is in micro amps, making it necessary to use an op-amp to amplify the signal.

Phototransistors have a narrower dynamic range and a slower response time, but it outputs in the milliamps range making them easier to work with.

In photo-resistors, as the amount of light increases so does the resistance. They have a linear response and are very cheap, however they have the slowest of the response times (25-50ms).



User Interface

The end user will need to be able to control the piezoelectric devices to move the laser beam. The device must allow for the independent control of two channels. This can be controlled digitally through a microprocessor or by analog means with two potentiometers.

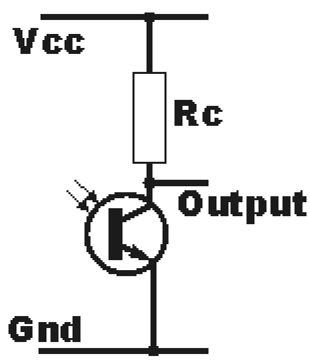
Design Concept 1: Laser Manipulated Robot- Laser Guided "Curiosity"

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.

Three Methods of Laser Guided Robots:

<u>Light Sensor/Phototransistor Eyes:</u>

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 #__.



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.

Scribbler Robot:

Parallax makes a commercially available robot called the Scribbler 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 1: Scribbler 2

Boe-Bot:

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 #__ shows the Parallax 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.

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.

Laser Actuated Remote:

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.

Pricing

The total price for the laser guided robot concept would be dependent on the price for the laser control as well as the additional costs associated with the robots and robot control. There are two choices that could be implemented if a preprogrammed robot were chosen for following the laser light. The Scribbler robot is a more cost effective robot but the Boe-Bot would allow for easier control of the motion of "Curiosity". If the second method were chosen a robot and a webcam would need to be purchased. If the light sensor array control method were chosen the additional costs would be a programmable robot and the light sensor array. Each method would have additional costs of under $200.

Design Concept 2: Satellite Transmission Game

Some satellites, like those from Cedrat Technologies, utilize piezoelectric smart material for micropositioning and vibration damping. The advantage to 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.

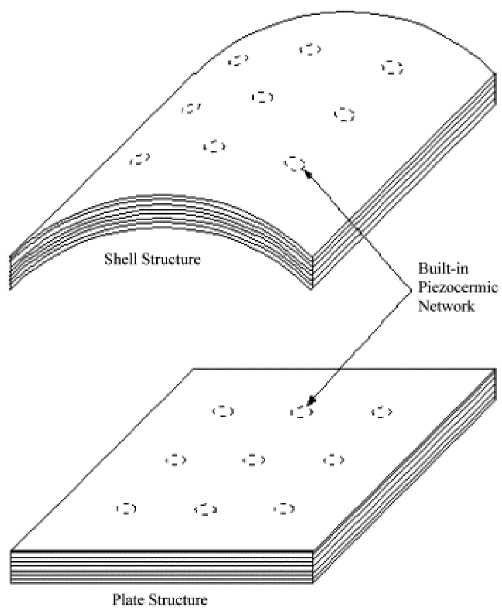
After collecting data, satellites need a way to send the data back to researchers and scientists on earth. This can be done by either a high or low gain antenna. The high gain antenna is used for sending a lot of data very quickly, while the low gain antenna transmits more slowly. However, the high gain 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.

Design Concept 3: Laser Activated Satellite Control

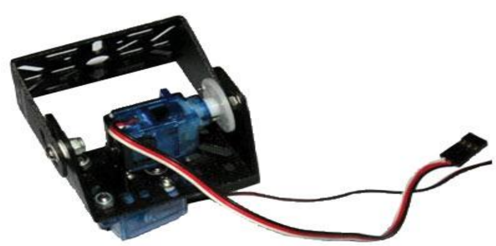
This design is based on the real life application use of smart material in satellites in space. Piezoceramics are currently used in adjustable antennas for satellite communications. An antenna with piezoceramic components is able to bend slightly when provided with voltage. The piezoceramics can change 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.



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

The exhibit is set to be 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.



Pan/tilt kit to be attached to bottom of reflective satellite.

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.

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

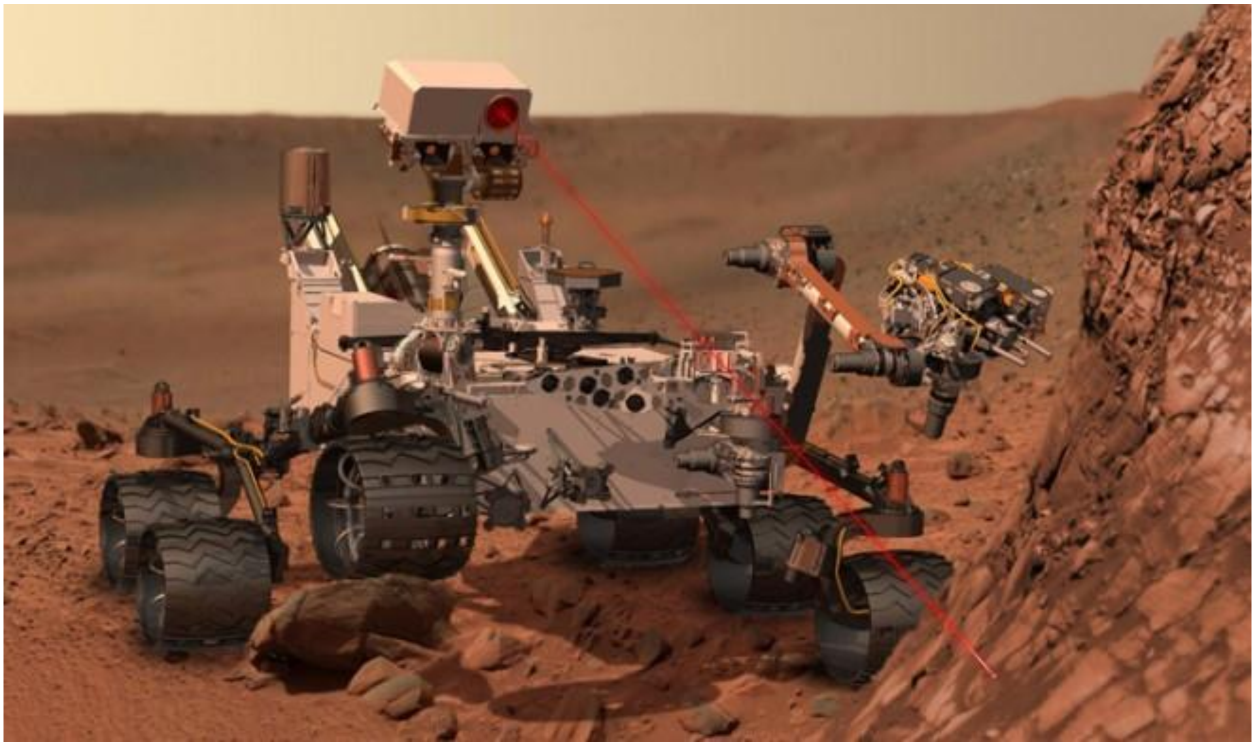
Some pros are that this exhibit resembles a real life use of smart material. Piezoceramics are used directly in satellite communications in space even if not in the same exact manner they are used in this project. Students would get a firsthand look at the advantages of such innovative material. Some 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.

Design 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 mar's 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 of 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.



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.

Decision Matrix

		Concept 1: Laser Manipulated Robot		Concept 2: Satellite Transmission Game		Concept 3: Laser Activated Satellite Control		Concept 4: Mars Curiosity Rover Chem-cam	
Specifications	**Weight**	**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**

Conclusion

After consulting with our advisor and sponsor at the Challenger Learning Center, a decision matrix was design and processed. Concept three, the laser activated satellite control, was the design that really enthused our sponsor when we presented it. After evaluating the designs in the decision matrix, this design was again selected to be the best design of the four. Next, the final components and detailed system design will be undertaken by the design team.

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