

**Drexel University Society of Physics Students**  
**Sigma Pi Sigma Undergraduate Research Award**  
**Dynamic 3D-Image Projection System**

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**Abstract:**

The purpose of this project is to create a working device as a proof of principle for a dynamic three dimensional projection system by creating a two dimensional version. Afterwards, an interaction system will be incorporated and the construction for a fully functional three dimensional projection system will follow. The construction of this 2D system will bring together students from different departments of the University together with physics students that are a part of the Society of Physics Students. This project will allow the participants to apply or learn basic physics concepts or topics such as linear and circular motion, torque, electrical circuits, optics, lasers, and programming.

**Introduction:**

The project that we had proposed and are currently working on is a unique approach in projecting dynamic three dimensional objects. Although our project may share some aspects of other 3D systems other companies and universities have created, it ultimately differs because of the fundamental method of how the 3D object is made.

**Technologies involving dynamic 3D display systems**

Many companies and universities have proposed and created 3D projection systems by different methods. The University of Southern California Graphics Lab has created their 3D projection system by rapidly displaying images of an object in all directions onto a spinning mirror. Keio University has created their 3D projection system by rapidly generating plasma luminous bodies in mid air to construct an object through laser induced breakdown. Companies such as Actuality Systems Inc, Holografika, Seereal Technologies, and Musion Eyeliner have also created their own methods of generating a dynamic 3D object. Actuality Systems employs the idea of projecting multiple images on a rotating screen similar to the University of California. Holografika and Seereal Technologies both use autostereoscopy, a technology which relies on voxels, objects that can alter in color and intensity to be displayed in different directions. Musion Eyeliner uses "Pepper's Ghost" technology, which utilizes a high definition projector and light thin screen. The drawback in each of these systems is limited interactivity. For example the user cannot move their hand into the projected image, which is one of the essential methods we use to interact with reality.

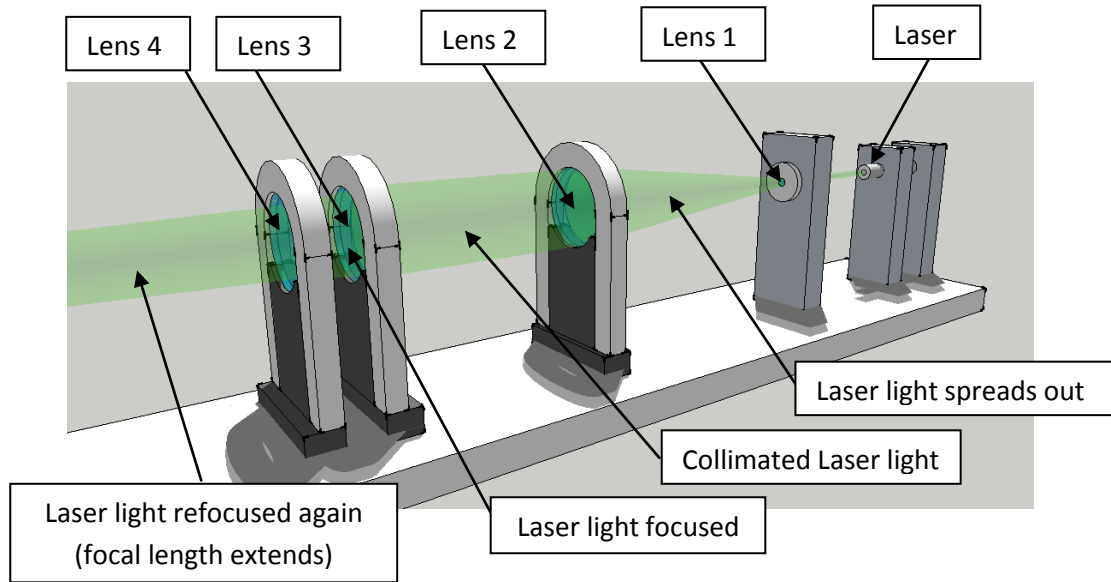
**Explanation of our current 3D projection system:**

We create an artificial three dimensional solid object out of light by rapidly moving a point of light in a region of water vapor. The rapid movement will be accomplished by using electric motors that hold mirrors in a particular design which will reflect light at desired locations. The point of light is created by an optical lens system made up of a total of four lenses. The first lens, labeled lens 1, is a concave lens, the second and third lens, are labeled lens 2 and 3 respectively, and are convex lenses, the fourth lens, and labeled lens 4, is a concave lens. A figure of the optical system is shown in Figure 1. Lens 1 will spread the laser light outwards and the lens 2 will collimate the laser light. Assuming that the region of water vapor is fairly uniform and that lens 3 and 4 focuses the laser light inside the water vapor, then the region of water vapor around the focal point will reflect more light than other regions of water vapor because more light is concentrated there. This region of water vapor that reflects the most light is referred to as the point of light.

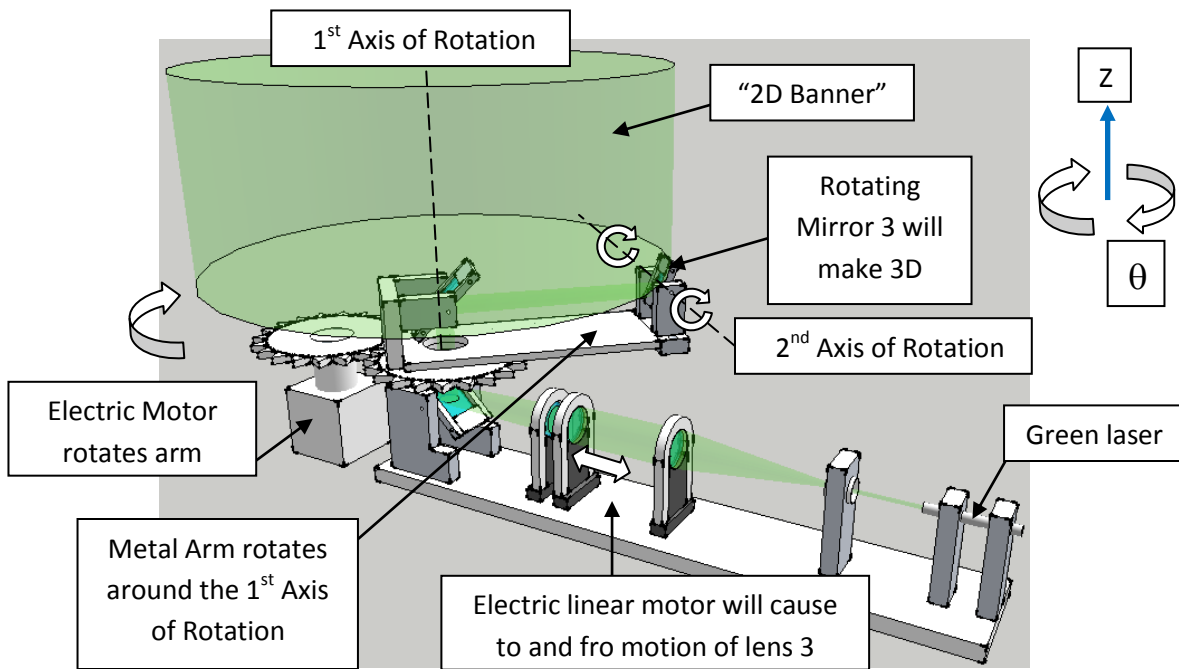
The rapid movement of the point of light is accomplished by using the design shown in Figure 2. By using a linear motor attached to lens 3 and moving it to and fro lens 4, the focal length will either extend or contract and therefore change the location of the focal point. This motion controls the first dimension of movement. The second dimension of movement is the rotation of the metal arm. The last dimension of movement is the rotation of mirror 3. Notice that if mirror 3 is kept at 45 degrees while the electric motor rotates the metal arm and the linear motor moves lens 3 to and fro lens 4 at a high enough speed, a "2D banner of light" will result.

Through the combined high speed motions of the linear motor, the rotating arm and the rotation of mirror 3, the focal point can be relocated at any location within a "3D cylinder. The overall size of the 3D cylinder is limited by the

length of the metal arm and the distance the focal length can extend. The moving parts of this project will move at speeds such that it will allow the projection of a "3D cylinder of light" if the laser is constantly on. This would be the maximum output of the device because all of the defined regions of space are illuminated. By knowing that the focal point can be relocated at any location within the 3D cylinder at such high speeds that it can create the illusion of a solid light cylinder, then switching off the laser at different times will allow the creation of any three dimensional object. Through programming on and off times of the laser, any dynamic or static image can be created within the defined 3D cylinder.



**Figure 1:** This is the optical lens system. Lens 1 spreads the laser light out. Lens 2 collimates the spread of laser light. Lens 3 focuses the collimated light to a focus. Lens 4 spreads the laser but in effect focuses the laser light to a point at a further location then lens 3 could alone. Lens 4 is a focal length extender.



**Figure 2:** The arrows show the direction of movement of the parts of the system. Notice that if mirror 3 is kept at 45 degrees, a 2D banner will result. However if mirror 3 is allowed to rotate, then all of 3D space can be covered.

## The novelty of our dynamic 3D projection system and its potential applications:

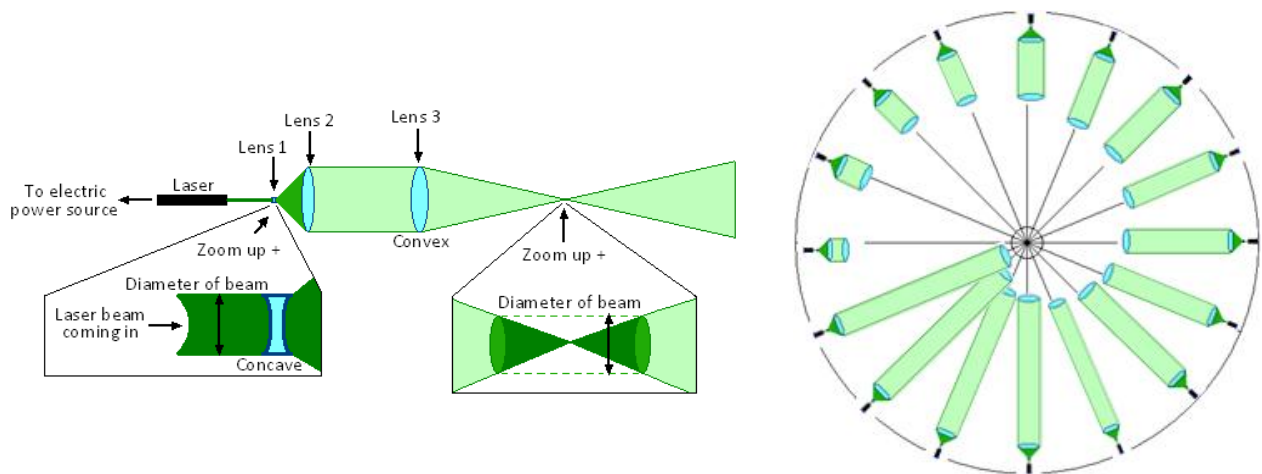
Our system does not require any special glasses to view the 3D object. It also allows any number of viewers looking at any angle or direction and distance, given that the distance is not so large that the device itself cannot be seen. Also, the system can be scaled larger, but not indefinitely, by essentially using larger or different lenses, motors, and mirrors. Moreover, the incorporation of different colors can be added by simply adding a frequency tunable laser. Lastly, the most notable aspect of our system is the interactivity with users that no other 3D system currently can allow. Since our 3D objects are created in real space and inside a non-harmful medium that is not contained, a tracking system can be added in to allow for true one to one manipulation of virtual objects.

There are many potential applications that this projection system can be used for and are definitely not limited to the following examples that are given. In the commercial industry the projection system could for example safely present the countless small products that exist; jewelry, clothing, tools, toys, food, etc, either statically or dynamically by being animated. In the medical field, PET, CAT, MRI, and X-ray scans of bodies can be visualized in real 3D space. In the entertainment industry, one can imagine an array of these projection systems inside a room that line the ceiling similar to how lights are in a room. The room can be designed to have a water vapor environment with a tracking system that monitors users inside the room. This room could then generate 3D objects in real space that users can interact with. This similar idea can also be used by the military for training purposes.

## Summary of work so far (How our original proposal changed/Complications/Current Status):

### Changes in original proposal/Our complications/What we have learned:

There are three major changes to our original proposal. The first change was the optical system that was originally proposed. The original optical system is shown as a top view below in Figure 3b and the components that make up Figure 3b is shown in Figure 3a.

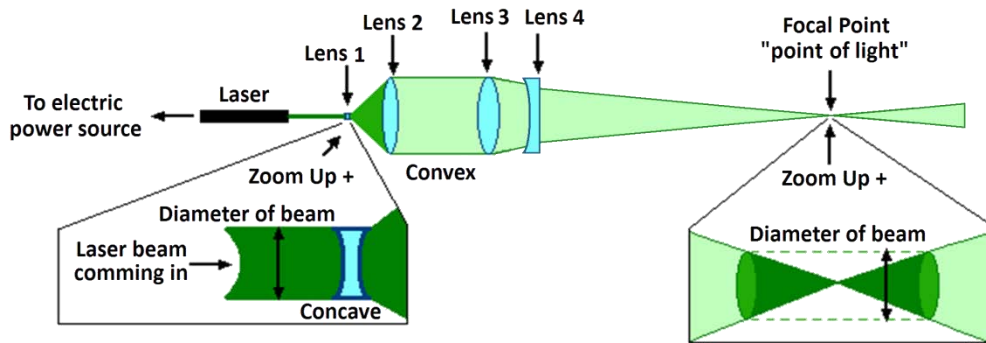


**Figure 3a (Left), 3b (Right):** 3a, shows how there are only three lenses that are used. 3b is the original optical system and it consists of multiple lenses and lasers arranged in a spiral pattern. This spiral pattern of lenses was the solution to be able to change the location of the focal point fast enough by using the idea of “splitting the distance”.

The original idea was to oscillate lens 3 to move the point of light. However, it can be seen that the distance lens 3 traversed to and fro lens 2 would be directly proportional to how much the point of light would move. The complications that was encountered here was that to be able to display a decent sized object, the focal point needed to move a significant distance overall. The optical system shown in Figure 3b accomplishes this task of increasing the distance the point of light could travel by using more lenses, lasers and a spinning central mirror. At the center of Figure 3b, a 45 degree angled mirror is positioned such that the laser light would be directed out of this paper. The central mirror would rotate at high speeds and would face a different laser and 3<sup>rd</sup> lens positioned 2 inches farther or closer depending upon which direction it spun. Each 3<sup>rd</sup> lens in each component would oscillate 1 inch for example. The overall

effect of combining the oscillation of each of the 3<sup>rd</sup> lenses and the spinning central mirror would enable the point of light to traverse a significant distance. This idea was named “splitting the distance”.

It can be seen that the original optical system would include a huge amount of lasers and linear motors to oscillate each 3<sup>rd</sup> lens and would be extremely complicated to implement. Rethinking of the process of significantly changing the position of the point of light came with the idea of a focal length extender. By adding in a 4<sup>th</sup> lens to the component as shown in Figure 4, the extra lenses, lasers, and linear motors would not be needed along with the motor to spin the central mirror. The addition of the 4<sup>th</sup> lens changed the location of the focal length and followed the equation given in Eq. 1. Through simple algebra, it can be seen that if  $f_3 = -f_4$ , then our resulting equation can be in the form of Eq. 2.



**Figure 4:** The optical system simplified by adding in a focal length extender. The changing distance between lens 3 and lens 4 will dramatically change the focal length of the system as governed by Eq.1.

$$\frac{1}{f} = \frac{1}{f_3} + \frac{1}{f_4} - \frac{d}{f_3 * f_4}$$

**Eq. 1 :** The resulting focal length,  $f$ , based on a collimated source of light incoming and the distance,  $d$ , between two lenses, in which case is our Lens 3 and Lens 4.

$$\frac{f}{1} = \frac{f_3 * f_4}{d}$$

**Eq.2 :** Finding two lenses that have opposite magnitude in focal lengths,  $f_3 = -f_4$ , will result in an overall focal length  $f$ .

The collimation of the laser light was done by using lens 1 and 2. Lens 1 was a 3mm diameter lens with a focal length of 9mm and Lens 2 was a 50mm diameter lens with a focal length of 200mm. The distance that lens 1 and lens 2 needed to be from each other was ~191mm in order to collimate the beam. This was calculated by using the same Eq. 1. and setting the overall focal length,  $f = 0$  and solving for  $d$ . To refocus the laser again we purchased Lens 3 which was a 50mm diameter lens with a focal length of 100mm, and Lens 4 which was also 50mm diameter lens but had a focal length of -100mm.

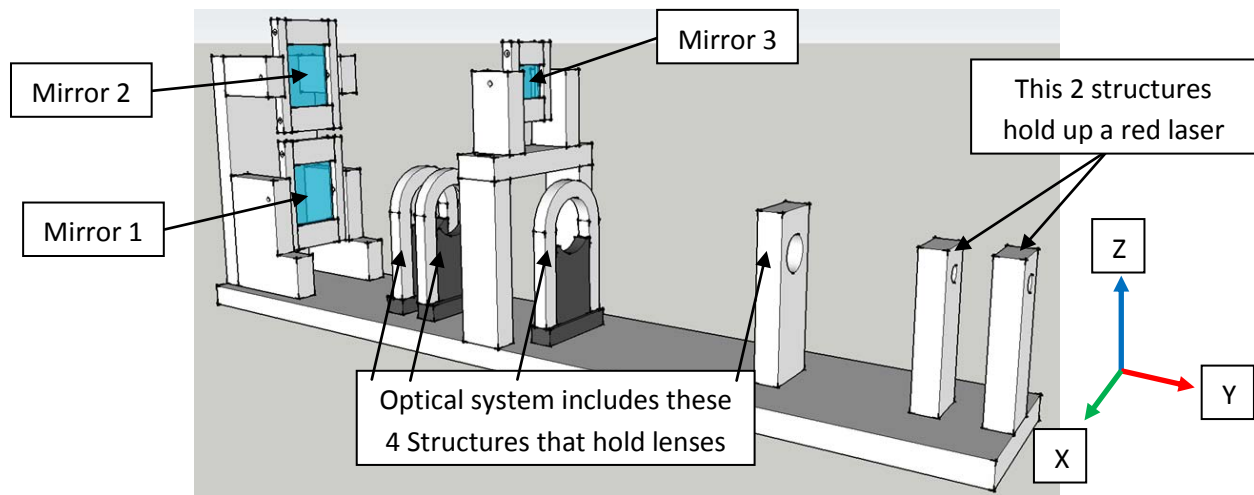
At this point, we had decided to purchase the lenses and experiment with the illumination for the point of light. Anxious to test this crucial aspect of our design, we embarked on a rough construction of home-made lens holders out of cardboard and foam board. This set up did not work well and what was determined was that we needed lens holders. We bought lens holders, but we realized after the fact of purchasing the lens holders that they were too large for our purposes. The lens holders had a thickness that forced Lens 3 and 4 to be a set distance away from each other that it severely constrained the distance in which we could move our point of light. This led to our second major change in design which was to redesign the lens holders so that lens 3 and lens 4 could be essentially touching and making the distance,  $d$ , between them ~ zero and thus be able to have a full range of distances to work with. However, just before the redesign of the lens holders the school term reached summer and progress slowed.

During the summer, a tedious effort was made to try to test the point of light, to see if the optics system consisting of four lenses worked out as our math had predicted. Foam board, scrap material, cardboard, along with lens holders were positioned carefully and the test for collimating and refocusing the laser light was successful. However, during this test, a humidifier was not present to actually see the point of light. Moreover a humidifier could not be used in

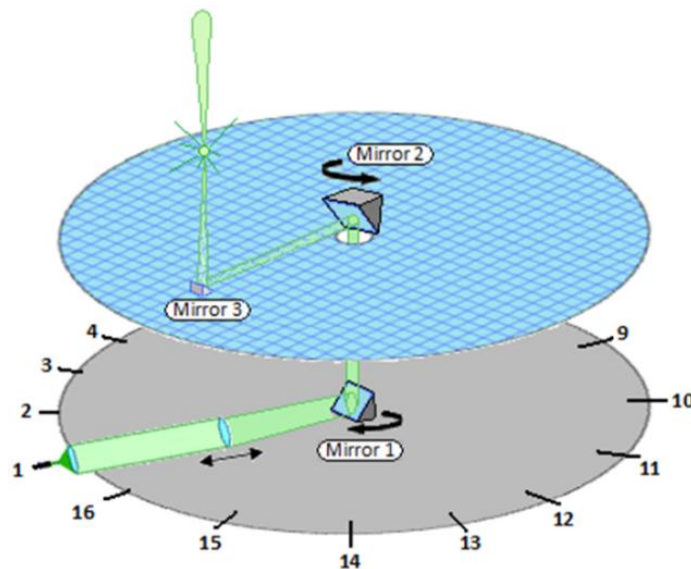
the laboratory we were constructing our project in because it would damage electronics in the room. It was unfortunate that the set up was a one shot deal meaning that it could not be relocated to another room at the time because there were no rooms really available at the time.

Work resumed beginning fall term 2010, and the design for a prototype to test for the point of light was designed as shown in Figure 4. The prototype was designed in such a way that it could be mobile and can relocate to different places if needed and can be easily modified to add in electric motors to complete the main objective.

Approximately during the design for the prototype to test for the point of light, the 3<sup>rd</sup> major change from the original design was done. The original design for the 3D portion was to include a plane of mirrors as shown in Figure 5. Each tiny mirror acted as the x-y resolution for the 3D object. It can be seen that the rapid movements of many tiny mirrors would be extremely difficult to engineer and after some brainstorming sessions the idea of simply rotating mirror 3 came about. The currently modified 3D projection system is shown in Figure 2.



**Figure 4:** This is the setup of the experiment that will allow us to test the point of light. This is the most crucial test.



**Figure 5:** The original idea included a plane of tiny mirrors that each could pop up and reflect light from mirror 2 to a designated location in the air.

## Current Status:

Our current stage of development for creating a “Dynamic 3D-Image Projection System” is in the building phase of making a reliable set up that will be able to test the creation of a point of light and will be able to complete this by early next year. This step is crucial to our project because it is the basis of how our approach will work in generating an artificial three dimensional solid object. We are in the process of machining aluminum parts as designed in the document attached named “Dynamic 3D-Image Projection System Prototype 00”. This setup, shown in Figure 4, allows us to rotate three mirrors independently in such a fashion that allows us to reflect the light traveling through the optical system to a desired position above the setup. Above this setup is the location of the water vapor region. Water vapor will be generated by using a humidifier that is stationed above and to the side of this set up. The amount of water vapor that is needed is best determined experimentally. What can also best be determined experimentally is the intensity of laser light needed by using polarizing films which will be placed at the structure that holds a red laser.

The generation of the point of light is an experiment that will determine the fate of this project. If the point of light looks successful, very bright spot in a small region of water vapor, then the next step will proceed. If the point of light looks reasonable, a noticeable bright spot in a localized region with a gradual decrease in light intensity, then the next step will also proceed. This ‘next step’ is to add a metal arm and placing mirror 2 and 3 on it such that they face each other. This metal arm will be located where mirror 2 currently is and will rotate by connecting an electric motor to the side. This will allow our project move into the 1<sup>st</sup> dimension of the projection system. If the test of the point of light fails, no possible way of making a region of water vapor brighter than other regions, then the project will come to stand still and a new approach will need to be brainstormed in order to proceed to the next step as mentioned.

While we are physically constructing our prototype, the programming side of this project is experimenting with a simple laser and an arduino controller that has the ability to turn the laser on and off at specified rates. Assuming that the point of light experiment is successful and the addition of the motor at mirror 2 and the linear motor at lens 3 function properly, the optimal method for using these motors are being brainstormed to achieve the 2<sup>nd</sup> dimension in our projection system. The optimal method is the answer to the questions; “How fast do our electric motors need to operate rapidly move the point of light to trace out a two dimensional image fast enough for a human to perceive these movements as solid?” and “In what fashion do we move the focal point in order to minimize the speed the motors need to operate at?” The answer to the first question and second question is still being worked out and will be presented partially.

Given that the human eye perceives a flashing image as relatively solid if it is at a rate of approximately 24 times a second, we want to use this number as our ideal rate in our calculations. But, as we discuss below, to project shapes at that speed poses problems for our system. We instead choose the more practical value of 1/12<sup>th</sup> of a second for our refresh rate. Using this value and projection limits of our machine, we can calculate the speed the rotational motor, for the spinning arm, and the linear motor, for lens 3, need to create a “2D banner”. This ‘banner’ is the intermediate step before we move onto the full 3D projection system.

We start by calculating the maximum possible projection which is a solid 2D banner. This resembles a cylinder and cylindrical coordinates will be used. This requires the focal point to travel every location possible in 1/24<sup>th</sup> of a second. We define the length of our arm to be 30 cm and the height of the banner to be 50 cm. We also estimate that the focal point will be the size of 1cm<sup>3</sup>. We know that the movement of lens 3 to and from lens 4 will allow us to control the height of the banner and the rotation of the arm will control the  $\theta$  angle of the banner. By ‘unrolling’ the banner, shown in Figure 6, we can picture how the motors will operate in such a way that will minimize the strain on them.

The horizontal axis length represents the circumference of the banner, which is  $30\pi$  cm, and the vertical axis length represents the height of the banner which is 30 cm. We know that the arm will need to make 1 frame, or one outline of the shape, in 1/12<sup>th</sup> of a second. For this to work, we need the arm to make 30 revolutions and lens 3 to make one outward or inward sweep within one frame. This is following the constraints that for every one rotation of the arm, the focal distance to change by 1 cm (the expected diameter of the focal point), so that a solid shape is created. From these measurements we can calculate the required rpm of the motors needed to move these parts. For the arm, we need 30 rotations in 1/12<sup>th</sup> of a second or 360 rotations in one second. This means we need a motor that is capable of spinning the arm at 21,600 rpm (60 secs/min \* 360 rotations/sec). For lens 3 we can utilize the scotch yoke mechanism, which gives us the ability to transform rotational motion into linear motion, which by construction does an entire outward and inward motion for every full rotation. This means we will only need half of the originally expected rpm, since covering the length of the cylinder once, in either the upward or downward direction, constitutes one frame. The specifications for this motor then become one rotation every 1/6<sup>th</sup> of a second, or 6 rotations per second, giving a required speed of 360 rpm.

As stated above, the human eye refreshes at a rate of approximately 24 times a second. This posed a problem for our system, because to have a frame made every 1/24<sup>th</sup> of a second required very high speeds, and impractically fast motors. There would be ways of balancing this, such as projecting smaller objects, but for this project we decided to lower

the refresh rate so that we could put more effort into successfully projecting points into space to prove the concept works. In the future, we will be able to incorporate more lasers into the design and in doing so we will reduce the load on the motors, allow us to slow them down while also projecting objects that appear more solid. Another concern that we anticipate to have in the near future is the uniformity of the water vapor medium. We are currently brainstorming ideas such as using the evaporating gases from dry ice or liquid nitrogen or using fans to continually circulate and evenly distribute the water vapor.

### **Future Work & Final Comments:**

The current plan is to finish the prototype that will test the point of light early next year 2011 and to move onto the 1 dimension which is adding in the central motor to spin the arm. Next electronics will be put in place and if the 1D turns out to be a success then soon after the 2<sup>nd</sup> dimension of the project will be added which is adding in a linear motor into the optical system that will move lens 3 to and fro lens 4.

The plan to finish the 1D step would be by the end of March 2011, and the 2D would be by the end of May or early June 2011. During the summer, many students will not be available and the work will pause. If the 2D banner is accomplished successfully then the final step of moving to the fully 3D projection system will follow by the addition of yet another motor to control mirror 3. The plan will be to accomplish this by the end of 2011 or possibly some date into 2012.

It is important to note that the amount of progress made so far in this project starting from an idea with a group of students with no background in real engineering is significant. During the attempts in testing the point of light, many new considerations and ideas came to mind to improve the system. Three major changes were made during this year and in our current construction of our prototype to test the point of light is underway. Many new skills in machining/engineering have been attained. We have also been able to get students from the computer science department at Drexel University to assist in the programming aspect of our projection system. Starting next year, 2011, engineers from Drexel's Engineering Department will be advertised to more closely for recruitment to finish up the construction of our prototype to test the point of light and to help design the next prototype for the 2D version of our projection system.

## Budget Info:

This following table shows how much we have spent so far.

Description	Quantity	Unit Price	Total
Polarizing Film (Decreases brightness of laser):	1	24.11	24.11
Laser Pointer w/ On-Off switch:	1	37.90	37.90
Three-Screw Ring Mounts	3	53.79	161.36
Lens Tissue (Cleaning and Maintenance):	1	10.54	10.54
Convex Lens 50mm dia x 200mm fl:	1	42.00	42.00
Convex Lens 50mm dia x 100mm fl:	1	42.00	45.19
Concave Lens 50mm dia x -100mm fl:	1	35.00	35.00
Mirrors 50mm x 75mm:	2	19.50	39.00
Mirror 30mm x 40mm:	1	12.50	12.50
Concave Lens 3mm dia x -9mm fl:	1	31.73	31.73
C-Mount (Holds 3mm lens):	1	42.73	42.73
Shipping, first time	1	19.15	19.15
Zinc-Plated Steel Flat Head Socket Cap Screw, 1/4"-20 Thread, 1-1/2" Length, Packs of 10	2	4.91	9.82
18-8 Stainless Steel Low Head Socket Cap Screw, 6-32 Thread, 3/4" Length, Packs of 25	1	12.40	12.40
High-Strength Aluminum (alloy 2024), Tight Tolerance, 3/16" Diameter, 1' Length	1	3.95	3.95
Multipurpose Aluminum (alloy 6061), 1" Thick X 6" Width X 1' Length	4	45.33	181.32
Multipurpose Aluminum (alloy 6061), 1/2" Thick, 6" Width, 1' Length	5	23.16	115.80
Shipping, second time	1	10.62	10.62
Large Electric Motor (to spin first mirror)	1	300.00	300.00
Electric Linear Motor (to move lens 4)	1	29.90	29.90
Small electric motor (to spin third mirror)	1	120.00	120.00
Humidifier	1	100.00	100.00
Micro controller	1	175.00	175.00
		Total	\$1560.02 (so far)

The price for the electric motors is an estimate because to figure this out, we would need to figure out the speeds in which the motors need to operate at and the load that the motor needs to work with. We do not know this information exactly yet and therefore can't determine the exact motor to purchase and therefore we estimate them to be around hundreds of dollars except for the small electric motor. More multipurpose aluminum is needed but the amount of it is still unknown because the design for the next step, 1D projection system, has not been done yet either. The price for the wires, humidifier and micro controller needs to be determined as well.

### Motor websites:

<http://www.alltronics.com/cgi-bin/item/28M025/55/Lin-Engineering-4018X-07-01-bipolar-stepper-motor>

<http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&item=390181619817#vi-content>