Mechanical Design of PlayLamp: A Minimally Intrusive Device for Recording the Behavior of Children At-Risk of Developmental Disorders

By

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I. ABSTRACT

This thesis paper documents the design process, decisions, and outcomes of the design of the physical form factor of PlayLamp, a device for video and audio recording the development of children at-risk of having developmental disorders in development at MIT's Media Lab Cognitive Machines Group. The physical form of PlayLamp is intended to be non-intrusive and have easy non-destructive installation while being aesthetically appealing and respectful of privacy. The end goal is to use the recorded information to develop computer models of behavioral patterns associated with these disorders.

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II. INTRODUCTION

PlayLamp is a new a camera observation system in development in the MIT Media Lab's Cognitive Machines Group designed to monitor children at risk of developmental disorders such as autism and is intended for in-home deployment. By recording the early development of these at-risk children within their homes over some preordained time period, it may be possible to ascertain behavioral patterns that might be precursors to these disorders. By taking the recorded data from a large sample subset of these children, one might be able to develop computational models of these behavioral patterns, which could eventually lead to early detection of these disorders. As surveillance devices are generally undesirable objects, especially in the home, it is necessary that the physical form factor of the device be non-threatening and minimally intrusive, aesthetically pleasing, and capable of being deactivated to respect people's privacy.

III. BACKGROUND

Playlamp is an offshoot of the Human Speechome Project[1], another Cognitive Machines project. In the Human Speechome Project, Deb Roy, the

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[1] Roy, Deb K, et al. The Human Speechome Project. July 2006. Cognitive Machines Group, MIT Media Lab. 3 May 2008.

director of the MIT Media Lab's Cognitive Machines Group had his home instrumented with cameras and microphones for the first three years of his child's life. Nearly everything that the child heard and saw during that time period was recorded. From this extensive amount of data, the group hopes to develop computational models of early language development.

Thought naturally turned to other possible uses for this type of data. One thought was that it could be applied to Autism and developmental disorder research. One application would be development of computational models for behavioral patterns associated with these disorders. However, if the device was to be deployed in a home with a child too young to be formally diagnosed with one of these disorders, how could one improve the possibility that the child recorded would develop one of these disorders later in life? The answer lies in that statistically, in families with more than one child, if the first child has a developmental disorder, subsequent children have a higher probability of being diagnosed for the same disorder and, as such, are deemed at-risk.

The intended end user for PlayLamp is a household with such an at-risk child. For PlayLamp, the deployment time would be shorter, and as one might expect, the end user would be less willing for holes to be put in the walls and ceiling and wires run throughout their home. Therefore, the device would have to be a standalone unit that did not rely on drilling any holes for installation.

<http://www.media.mit.edu/press/speechome/speechome-cogsci.pdf>.

Because in order to be useful, the video recorded would need a field of view that covered an entire room without severe obstruction, an overhead camera would be necessary. A secondary camera recording across the room at slightly above the height of a young child was also desired to give another recording viewpoint. One logical design for the form factor was one similar to an armed floor lamp, with a main vertical shaft and a long cantilevered arm, with cameras and microphones in place on each. This device would need to be easy to operate and install, aesthetically pleasing, and as non-obtrusive as possible. This project represented a significant design challenge, as it would integrate mechanical, electrical, and industrial design considerations as well as design for manufacturing, usability, and human factors.

IV. METHODS

IV. 1. PRELIMINARY DESIGN WORK

A great deal of initial designs were sketched for possible form factors of PlayLamp. Initial designs focused mainly on a two bar arm design, because of added stiffness bonus associated with having two bars above and below the bending moment center, leading to a much higher bending moment of inertia. This design did not lend itself to adjustability, however, so this concept was replaced with a single bar with a tensioning cable. Many of these designs were also modeled with clay, paper, and other materials. Also determined early on from an unwieldly prototype was that if the camera head were heavy, the base of the lamp would have to be extremely heavy or have a very large foot pad base. The vertical shaft also had the risk of deflection. The more elegant solution was to clamp the main shaft of the lamp to the floor and ceiling.

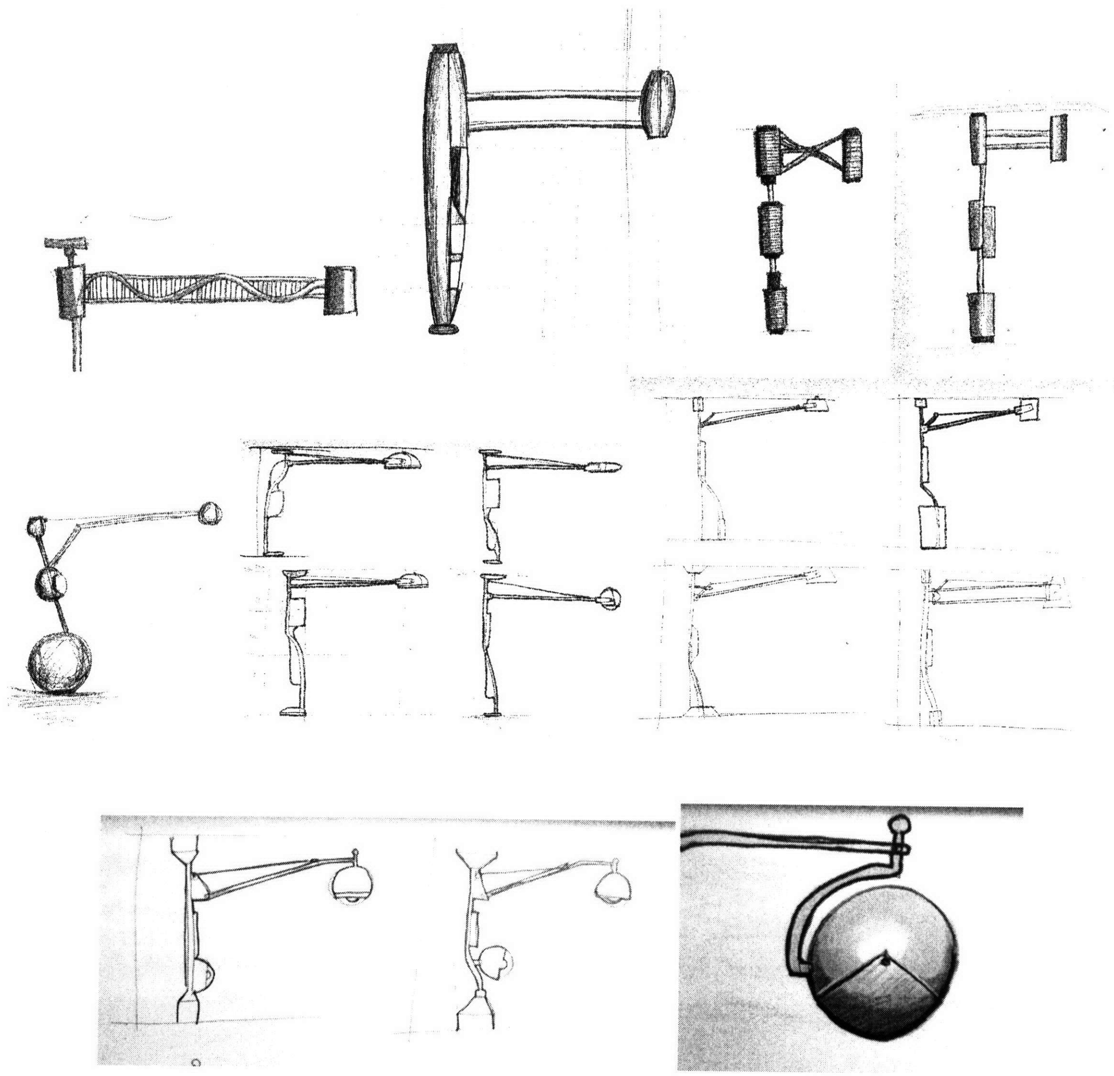

Figure 1: PlayLamp Concept Sketches

IV. 2. PLAYLAMP HEAD

It was necessary that the camera head be as small and lightweight as possible to minimize deflections of the cantilevered PlayLamp arm. Compactness would also help make the device less obtrusive and ominous. Further design and functional requirements were that the camera have a visible shutter mechanism as a physical indicator that the camera was not recording, and that camera head would be able to house the camera, microphone, and the related circuitry associated with each. Also, the camera made use of a fisheye lens, which has a rounded shape and must extend past the head structure to avoid vignetting due to the wide angle of view.

As a result of these design considerations as well as aesthetic ones, a hemispherical design was chosen to maximize space inside the head while keeping it compact overall. Another spherical sectioned shell would rotate around the outside to act as a shutter mechanism, so that when closed an entire sphere would result. This gives plenty of clearance for the lens, and means that not much of the internal space of the camera head would be dedicated to the shutter mechanism. Components inside the head would be mounted to a sheet of acrylic on the inside.

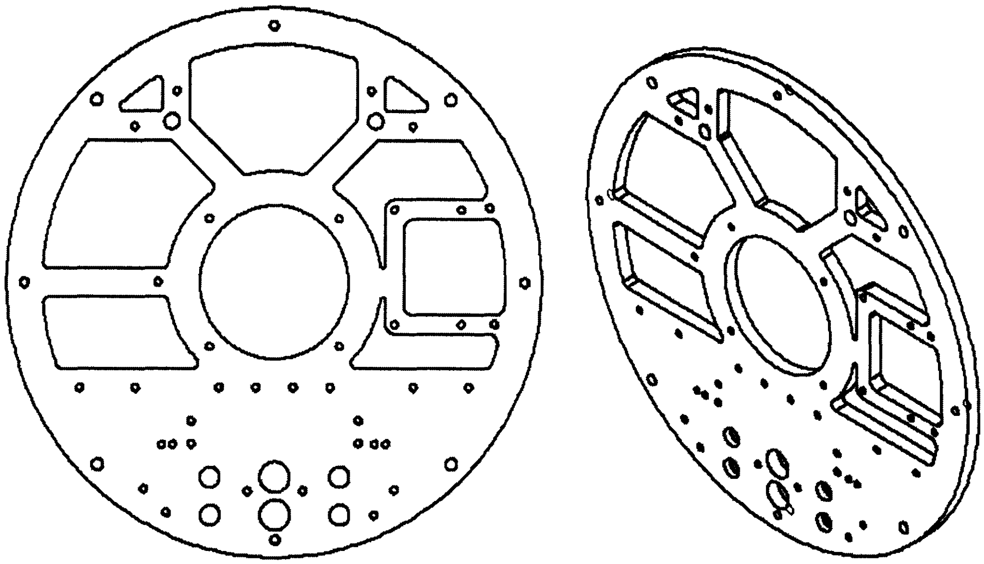

Figure 2: Acrylic Mounting Plate

This ring of acrylic would be manufactured using a lasercutter, which allowed for multiple iterations to be modeled and prototyped to ensure that all components fit in the minimum amount of space possible.

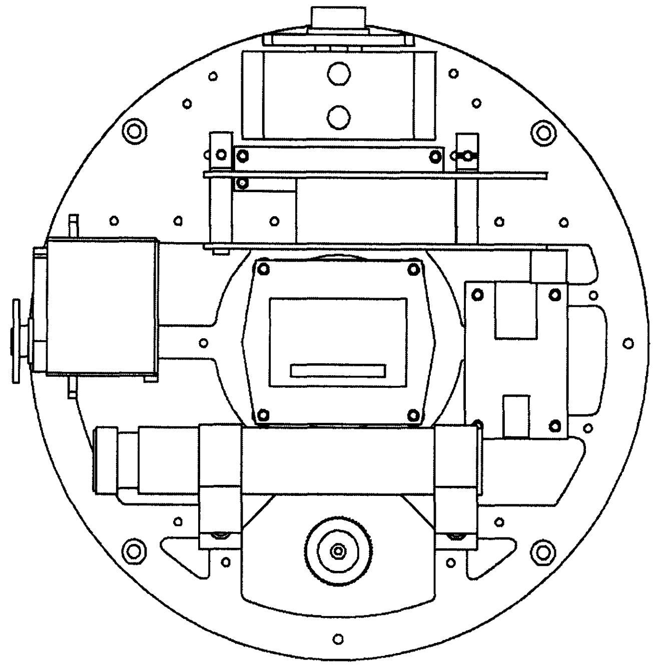

Figure 3: Acrylic Plate with Components Mounted

The limiting component was the microphone, which because of its large XLR connectors, required a great deal of linear space. The mounting plate has holes precut for tapping or pass-throughs. It also features openings, which serve as a standoff for the servo controller, a pass through for the camera lens, a pass through for the microphone, and also help to reduce weight. Special attention is made to ensure that all corners in the design are rounded to remove stress concentrations in the material. A number of extra bolt holes are included for attaching points of strain relief.

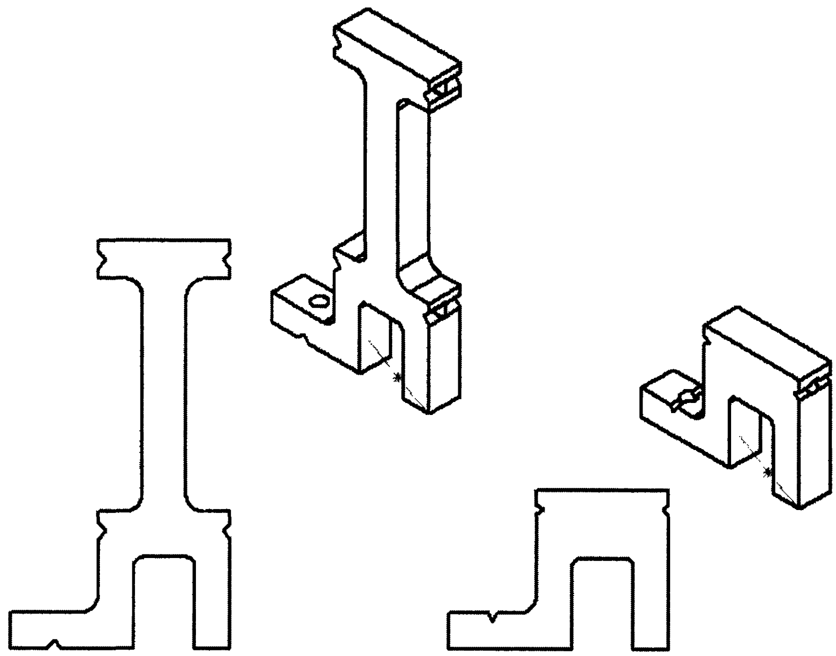

Figure 4: Camera Circuit Board Standoffs

Custom acrylic standoffs were designed to mount the camera's circuit boards to the mounting plate. The standoffs raise the boards, hold them together, provide a through hole for cables to pass underneath, and turn the board 90 degrees across two axis to conserve space. These are also manufactured out of acrylic using the lasercutter. Several holes must then be drilled and tapped. The camera mount was achieved simply by using premade aluminum standoffs screwed into the mounting plate. A small breakout board is cut from a larger circuit board and mounted to the acrylic plate. The wires from the different components are soldered into it then corresponding wires run from this board to a Hirose circular connector, mounted to a plate and then to the shell of the head. The microphone used is an AKG C562 CM Boundary Layer Microphone. The microphone is threaded, and is attached with a nut to another plate of acrylic bolted to the bottom of the mounting plate.

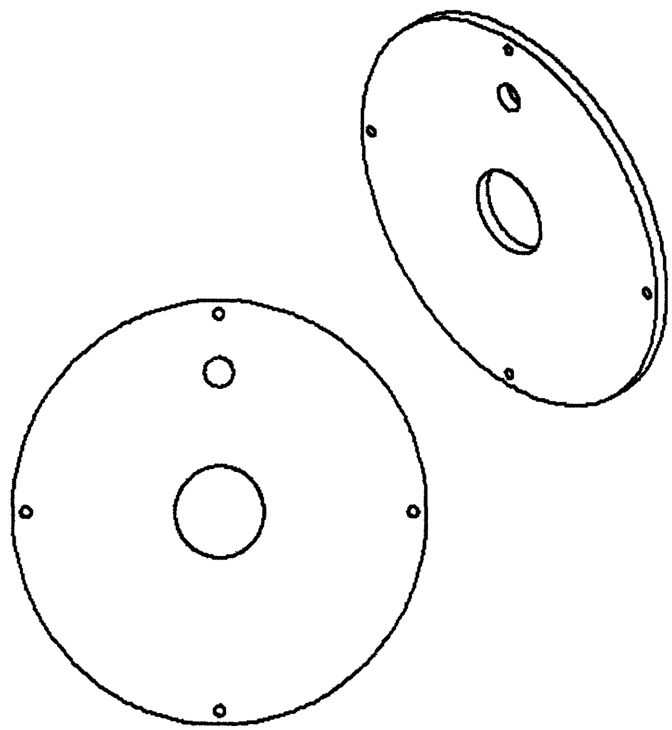

Figure 5: Acrylic Plate with Openings for Microphone and Lens

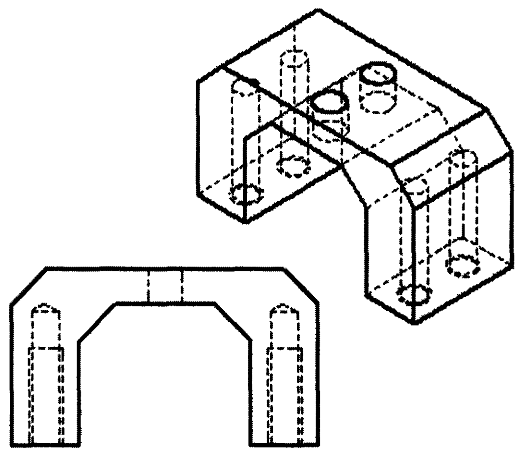

Figure 6: Aluminum Block Attachment

Also attached to the mounting plate is a piece of aluminum, which serves as a connection point to the short arm that connects the head to the frame. This piece is waterjetted then machined to remove the kerf left by the waterjet process. 6061 T6 Aluminum was chosen for its strength to weight ratio, corrosion resistance, and easy machine-ability. Using these aluminum pieces to connect directly to the acrylic rather than the plastic shell takes the load off of the shell.

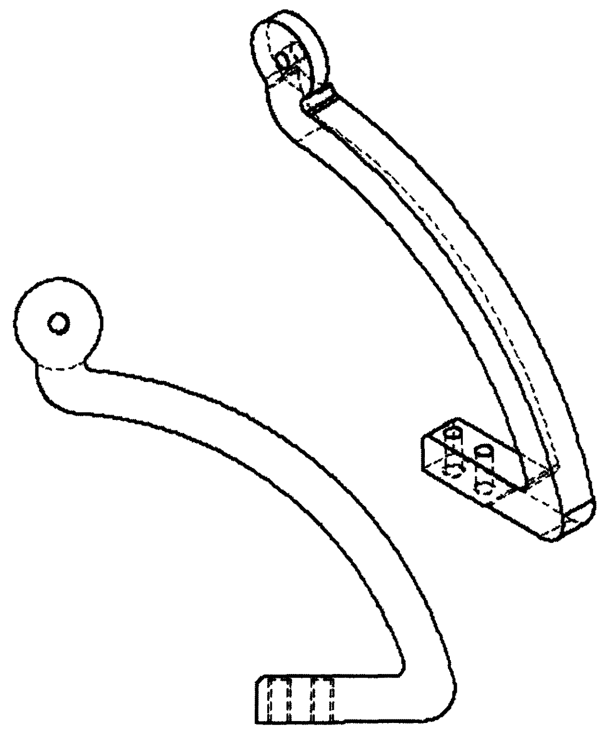

Figure 7: Small Aluminum Arm

Bolted onto this aluminum block is a small aluminum arm, which connects either to the PlayLamp arm end piece or a connector for an 80/20 framework. This small arm also features a threaded hole by the circular end. This allows the Playlamp end piece or 80/20 connector to act as a bearing, and a small handle can pass through and thread into the arm's hole. This acts as an adjustable joint for altering the angle of the camera. Some basic finite element analysis was conducted on this arm to determine how thick it needed to be. Assuming a head weight of 20 lbs, at ½ inch thick, the aluminum arm deflected only about 1/1000th of an inch and experienced no plastic deformation.

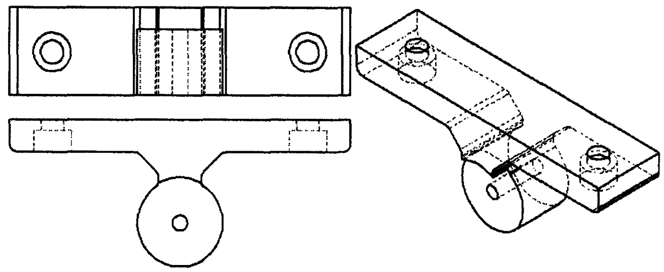

Figure 8: 80/20 Connector with Bearing for Arm

The 80/20 connector allows for easy linear translation of the camera on an 80/20 aluminum extrusion frame, using two small handles with threaded ends passing through the bolt holes on the flat flange and threaded into 80/20 nuts. Loosening these handles allow for linear translation of the entire head unit.

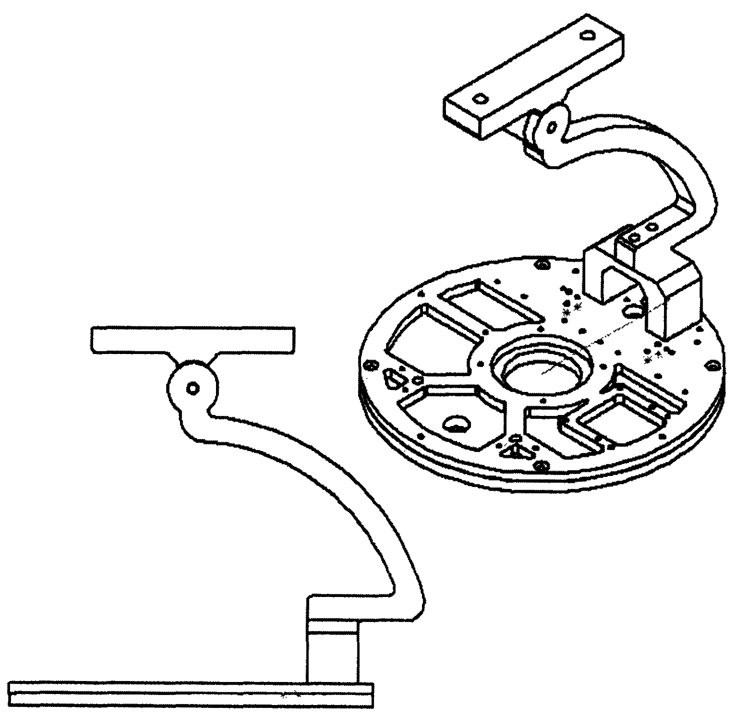

Figure 9: Assembly of Aluminum Pieces Plus Acrylic Plates

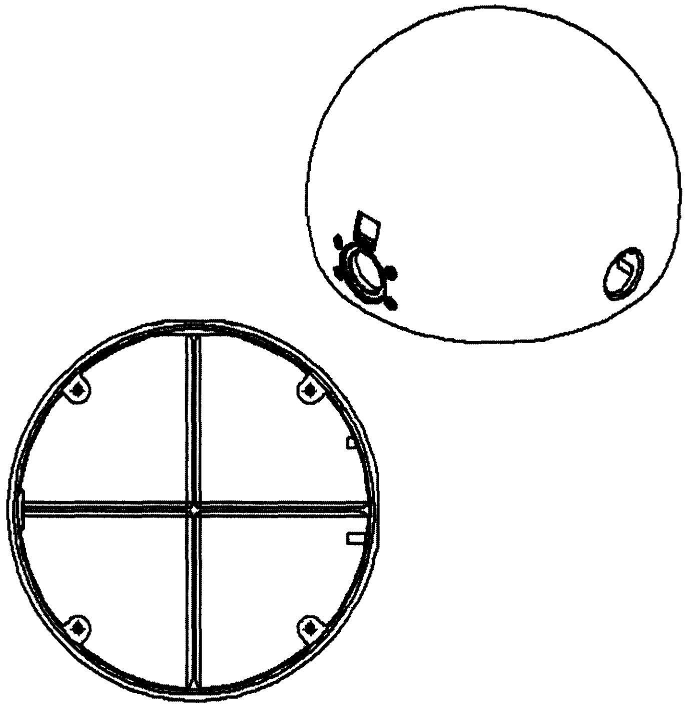

Figure 10: Bottom and Isometric Views of PlayLamp Head

The head's main shell is a thin-shelled, plastic sphere cut away at slightly more than a hemisphere. The interior, rather than having an overhang from the spherical shape, consists of a cylindrical section capped with a dome. This was done to help ensure easier manufacturability in future revisions. The main shell has some structural components as well.

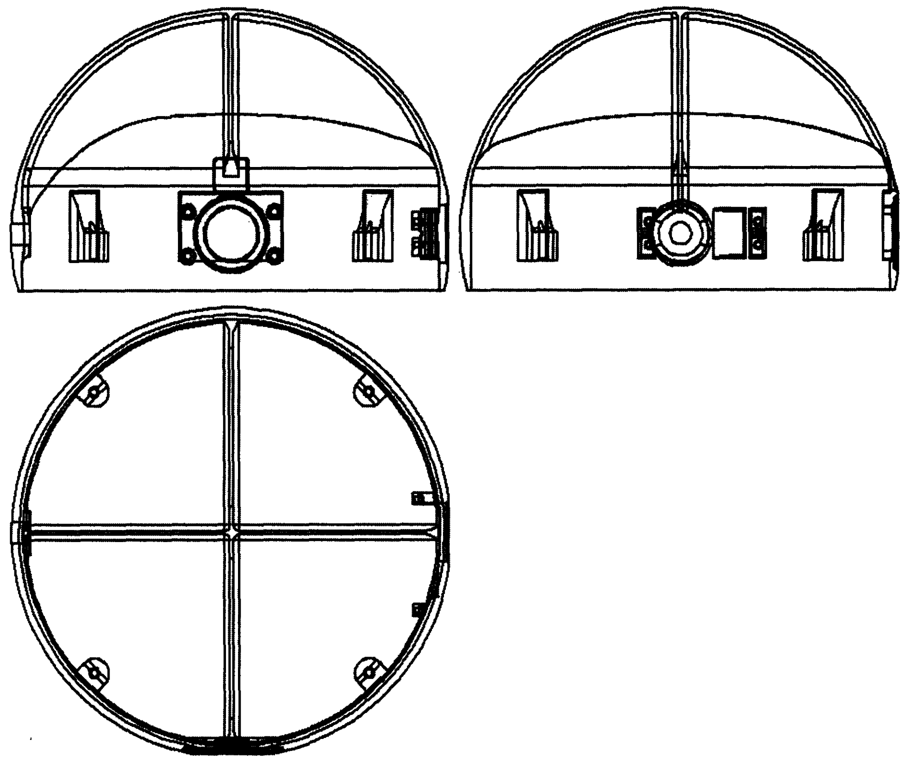

Figure 11: Sectional Views of PlayLamp Head

It features a mount for the servomotor that sits opposite an opening, which acts as a bearing surface for a small aluminum shaft connected to the rotating outermost shell. By making these features a part of the shell, it helps to ensure good alignment of the rotational axis of the outermost shell, and good concentricity of the two shells. The shell also has a mounting point for a small plate holding the Hirose circular connector receptacle. Four extensions from the wall with threaded bolt holes act as attachment points for the acrylic plates. Two intersecting ribs across the inside ceiling of the shell help to give the shell structural strength and help prevent warping and cracking when loads are applied to it.

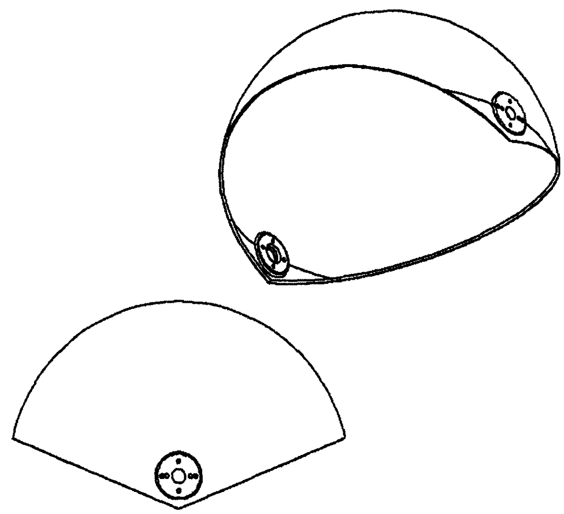

Figure 12: Rotating Outer Shell

Another thin-walled spherical section rotates around the outside of the shell. This outermost shell acts as the shutter mechanism for the PlayLamp head. It has two cylindrical mounting points, one for the servomotor and one for an aluminum shaft, which sits in the bearing surface of the main shell.

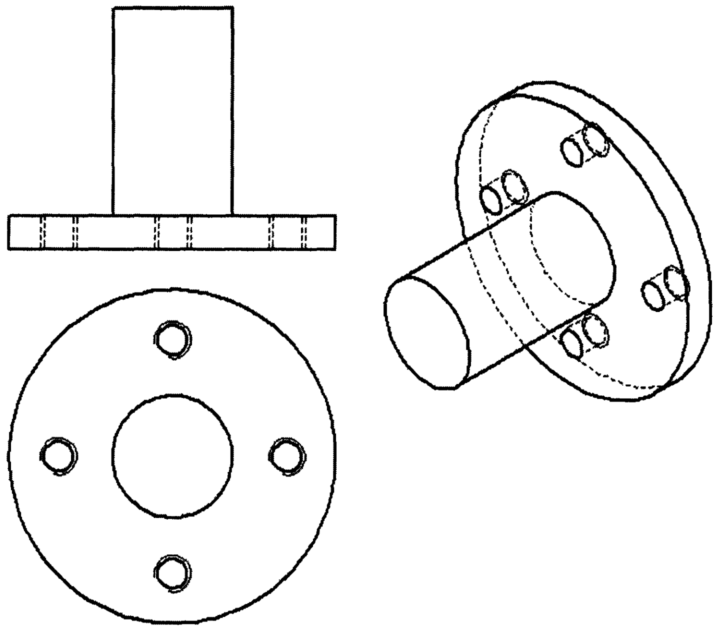

Figure 13: Aluminum Shaft

The angle at which it is cut means that when closed, the outer edges completely enclose the acrylic plate portion of the PlayLamp head.

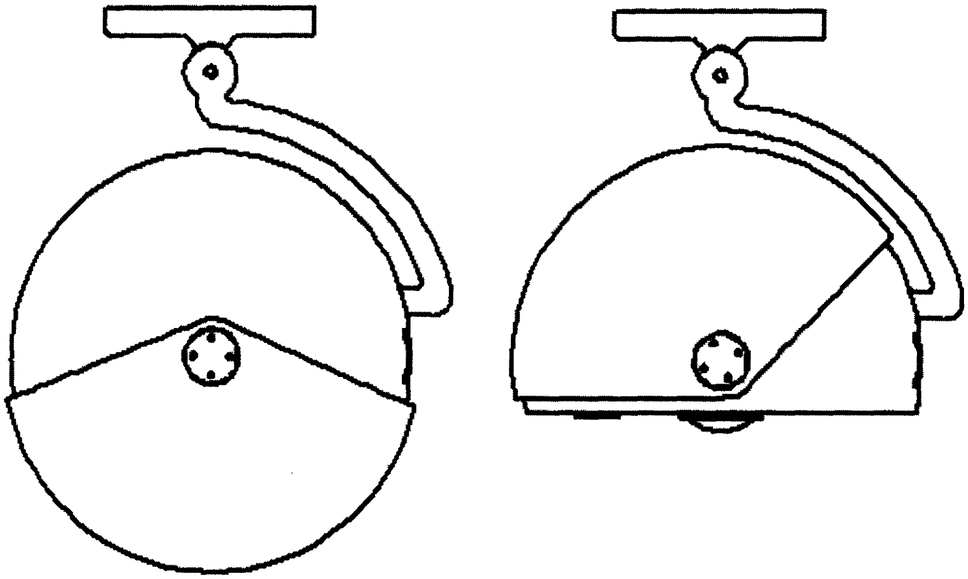

Figure 14: PlayLamp Head in Closed (Not Recording) and Open (Recording) Configurations

Because a run of only one prototype was to be produced, 3D Printing was chosen as the manufacturing process for the shells. While an expensive process due to high material costs, it is still cheaper than creating the tooling for injection molding. However, if larger production runs are done later, the same basic head design with a few adjustments can be used to either make a mold for injection molding or some other form of molding such as polyurethane molding. The structural features inside the shell such as the servomotor mount, bolt attachment points, etc. would need to be extended vertically towards the ceiling of the shell such that there are no overhangs. This was not done in the current model to conserve material. Then necessary holes could be machined in the sides afterwards. Alternatively the shell could be split into two halves with their own molds. These could either snap into each other or be ultrasonically welded to each other.

Because of the large number of cables that would be running out of the head to control and power the components within, it was decided to instead have all of these run in a single unified multiconductor cable. 18 Cables were required for each head, 8 for ethernet, 2 for camera power, 5 for USB, 3 for XLR. A 20 conductor 22 AWG multiconductor was found and 20 contact Hirose LF circular connectors were selected for their easy to use bayonet locking mechanism, small size, low cost, ready availability online, and built in strain relief features. Both the multiconductor and the circular connectors have power ratings that exceed those necessary for the components inside the head.

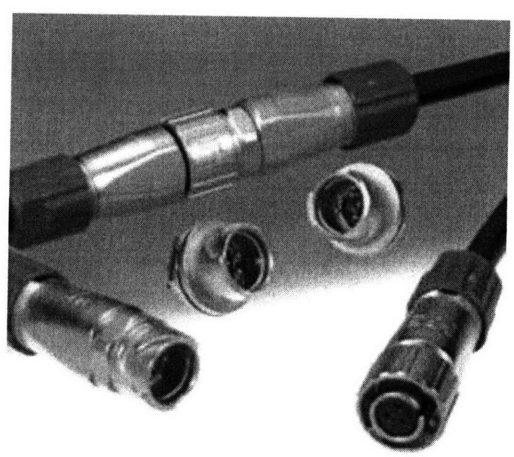

Figure 15: Hirose LF Circular connectors.[2]

Ultimately for the head, mostly rapid prototyping tools were used for construction of head components so that certain parts could be remade quickly and easily as needed.

IV. 3. PLAYLAMP ARM

PlayLamp needs to accommodate for the great variety of room sizes of the end user. The arm for PlayLamp consists primarily of a bent hollow tube and a tensioning cable to help prevent deflections. The ends of each tube are plugs that screw into the ends. These plugs have a clearance hole for a shaft or the screw that goes into the small arm of the PlayLamp Head. The arm also has two openings at each end machined out of the top or bottom face. These are points where the multiconductor cable is fed into the tube from one end to the other. Welded to the outside of the tube is a thin sheet of steel, which has a hole drilled in it. The tensioning wire passes through the hole, wraps back and ties to itself. Also welded to the top of the arm close to the PlayLamp head is a small metal ball. The angle of the arm is adjusted so that the metal ball contacts the ceiling, helping to stabilize motions of the arm and head. The other end of the

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[2]"Series Description." Hirose Connectors. 3 May 2008 <http://www.hirose-connectors.com/connectors/H205SeriesGaiyou.aspx?c1=LF&c3=3>.

arm has another plug through which a shaft is fitted, acting as a pivot for the arm and allowing it to raise and lower.

The pivot portion consists of a sheet of metal bent around the main PlayLamp shaft and welded to it. This section also has an attachment for the tensioning wire on a rotating shaft with a worm gear attached to it. The worm gear allows the cable to be shortened or lengthened, without being back driven. A hex rod welded to the back of the worm's shaft allows either a socket wrench or a drill to be affixed and, when rotated, winds or unwinds the cable. Winding the cable raises the head, allowing a greater angle of view for a larger room.

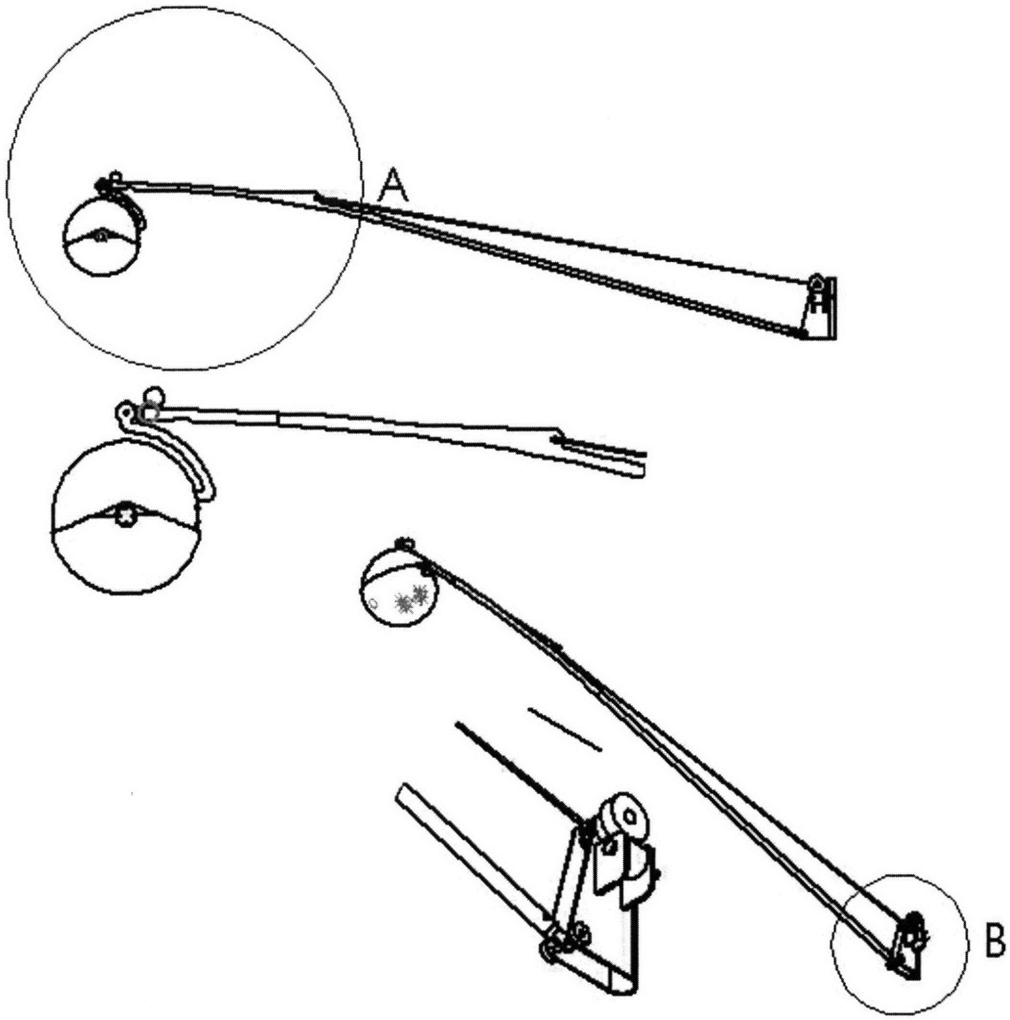

Figure 16: Arm Assembly

Detail A: Small Welded Ball

Detail B: Worm Gear Assembly with Arm and Wire Spool Shafts

For the material of the arm, chromed steel was chosen. Chromed steel is relatively cheap compared to aluminum, has the strength and stiffness benefits of steel while having a beautiful surface finish, and from research done online, tends to be one of the most common materials used in designer floorlamps. To help determine the thickness and material for the beam, first it was necessary to make sure the inside of the arm had room for the multiconductor cable to pass through. Bending moment analysis was then conducted using Matlab to determine the amount of deflection for different materials, inner and outer diameters, and head weights for a given angle of the tensioning cable. Please see the Appendix A.1 to see the Matlab script.

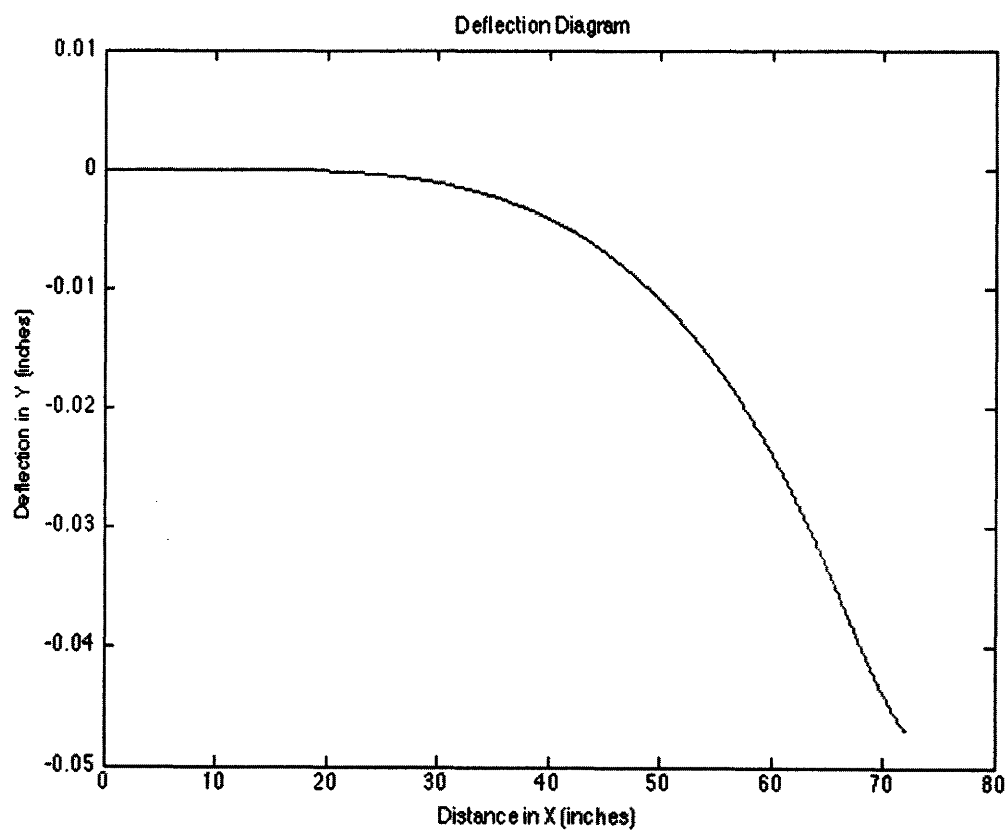

Figure 17: Arm Deflection for OD .625", 1/16" thickness Aluminum

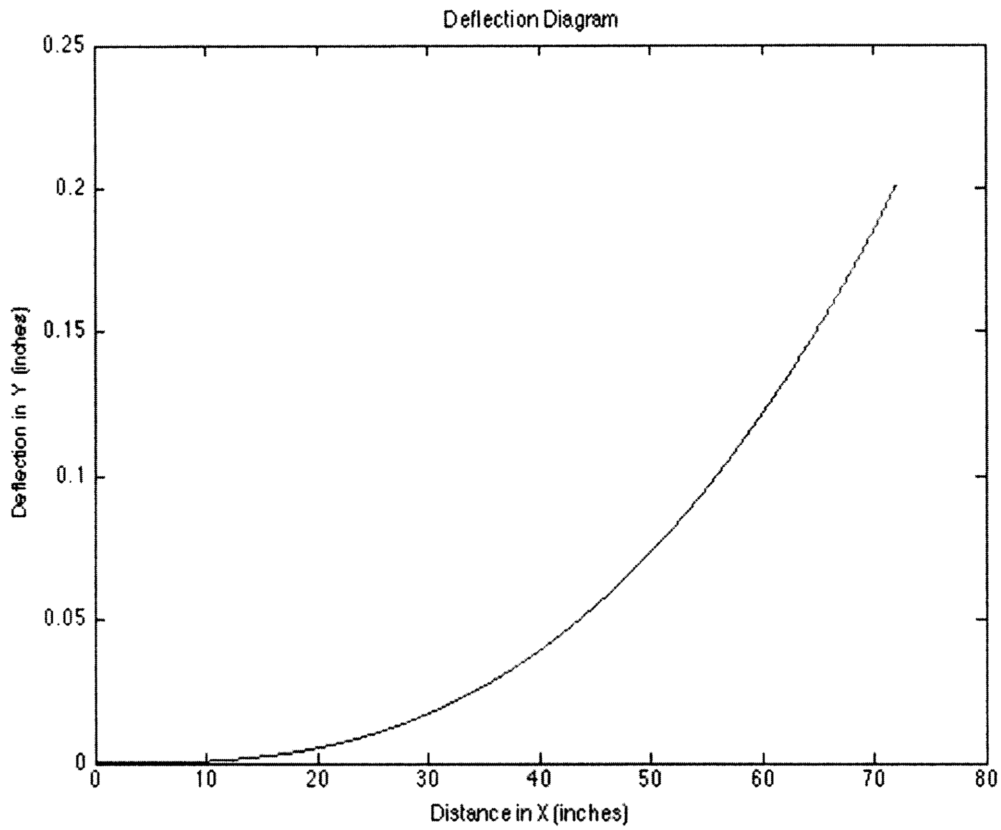

Figure 18: Arm Deflection for OD .625", 1/16" thickness Steel

IV. 4. PLAYLAMP MAIN BODY

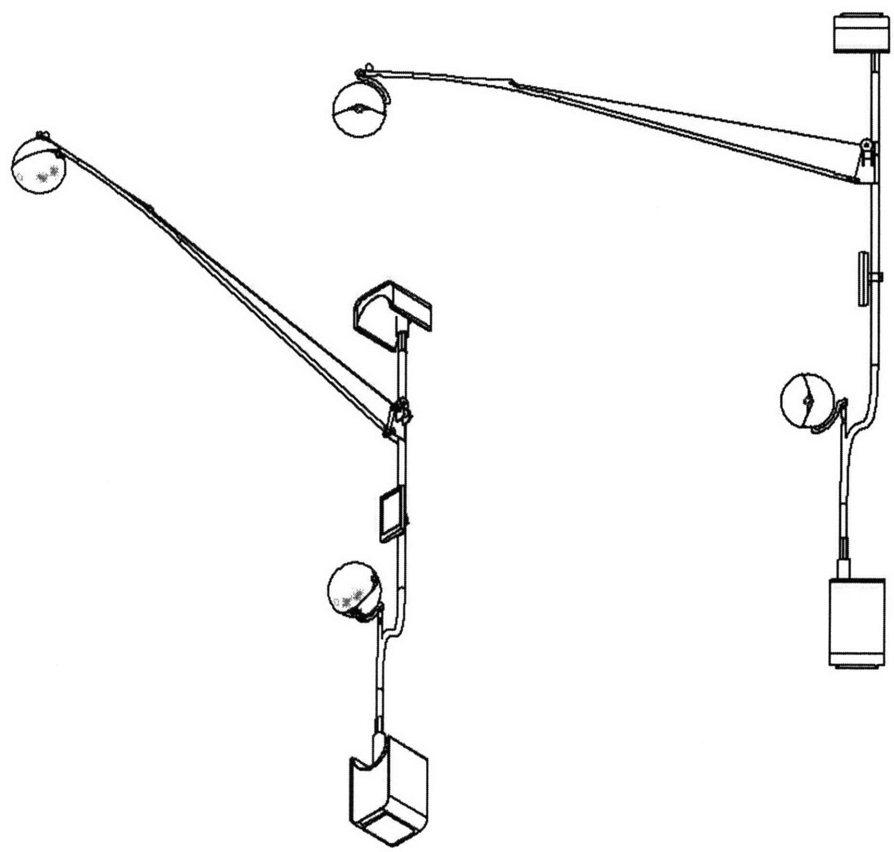

Figure 19: PlayLamp Assembly

The main body consists of a bent hollow chromed steel rod. The ends of this rod are threaded on the inside diameter. A hex rod with threaded ends is screwed into each end. On the other end of the hex rod is another hollow steel tube that has a slightly larger outer diameter for added stiffness. The Larger diameter steel tube fits through circular openings in the top and bottom feet and is welded into the top and bottom plates. The hex rod's threaded ends are threaded in different directions, one left handed and one right handed. This allows the hex to be turned and push the cylinder shafts apart uniformly and without causing the feet to rotate. This mechanism allows the PlayLamp to clamp between floor and ceiling for stability. This clamping means that the main shaft can be thinner and the feet smaller in profile and weight. The end user can make this adjustment simply by using an appropriately sized wrench. For dramatically different sized rooms, cylinders with one end with a threaded outer radius and one end with a threaded inner radius can be inserted between the hexagonal rod and the larger radius cylinder rod welded to the feet.

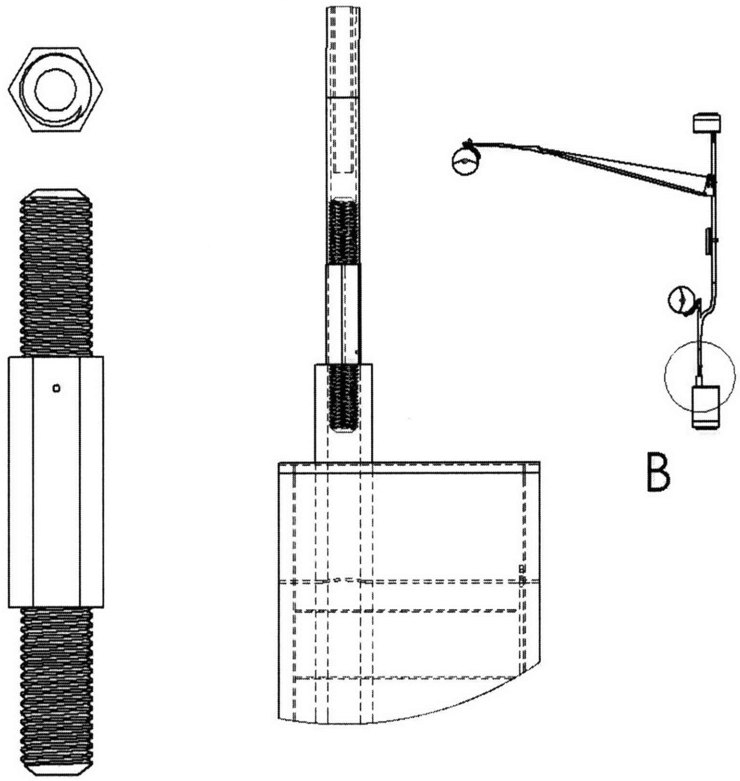

Figure 20: Threaded Cylinders and Threaded Hexagonal Rod

The bottom foot also acts as a containment unit for the different internal components of the PlayLamp. The shell of the unit is built out of bent sheet metal. The concave curve on the top side echoes the circular shape of the PlayLamp head unit. Shelves are welded to the interior. The shelves have a circular cutout for the hollow tube passing through the containment unit. They also have openings for cables to pass through to different levels. Also welded to the interior are several threaded bolt holes for attaching a plate to the back of the unit. The back plate has openings for cables to pass out of the device. The back panel can be removed for maintenance or replacement of the components inside. The front panel does not need to be removed and may simply be welded. To the bottom of the sheet metal shell is welded a thick sheet of metal for strength and stability. A rubber pad is glued to the bottom of this sheet to prevent slipping.

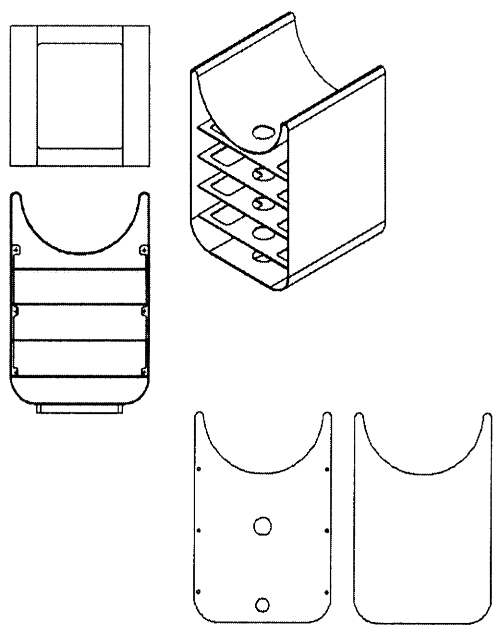

Figure 21: Bottom Foot Containment Unit

The top foot has very similar construction to the bottom foot, but does not need to hold anything, and so is just an empty shell.

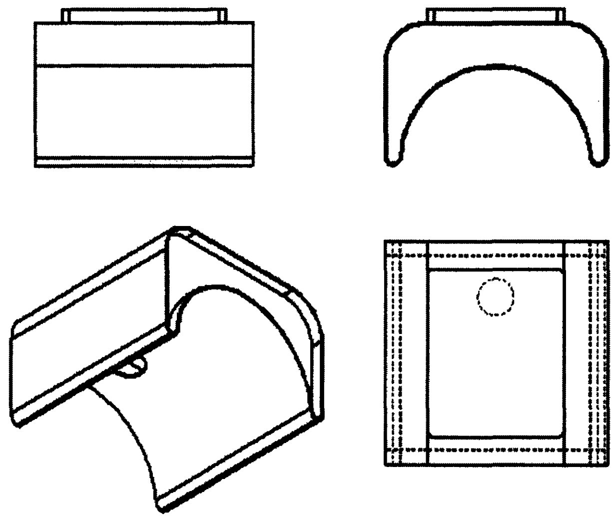

Figure 22: Top Foot Unit

IV. 5. COMPONENT SIDE BREAKOUT BOARD ASSEMBLY

A simple mount for the breakout board was created with standoffs for the board. It also has mounting areas for strain relief, and a back wall with Hirose Circular Connector receptacles.

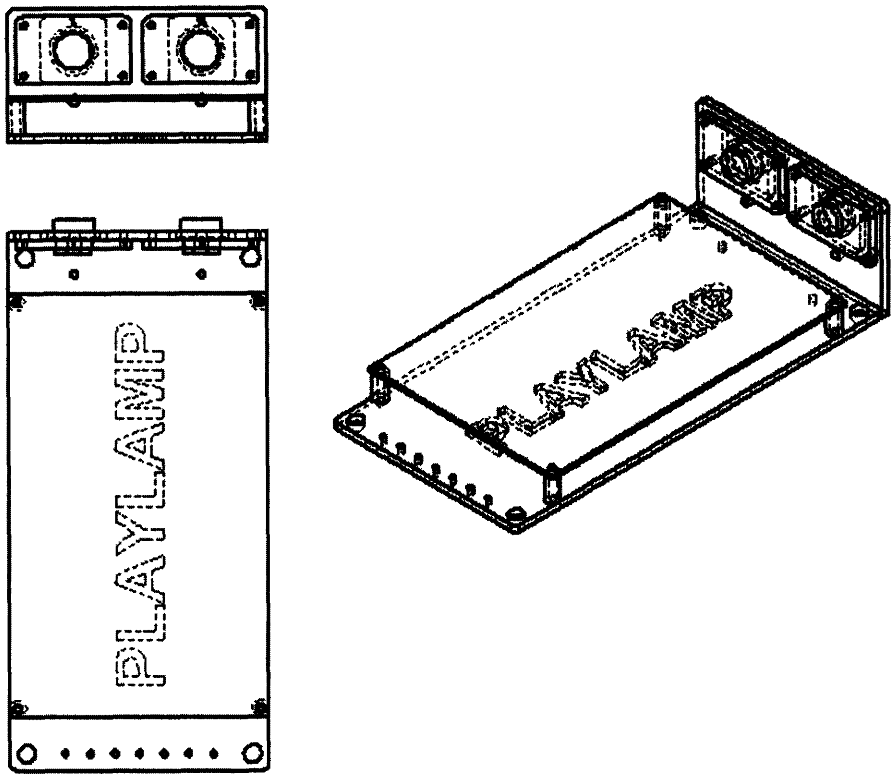

Figure 23: Breakout Board

V. CONCLUSION

The goal of this thesis project was to design the physical form factor of PlayLamp, creating a solid model of the overall design, and actually manufacturing the head component. The PlayLamp design needed to be functional, robust, and aesthetically appealing, while remaining unobtrusive and have a clear visual indicator when the device is recording. These tasks were completed successfully with a functioning head unit with spherical shape and shutter, and an aesthetically pleasing and functional solid model of the overall PlayLamp. It is possible that some modifications may have to be made when it comes time to actually manufacture the PlayLamp body due to material and labor costs, or manufacturing difficulties. For mass production some additional simplifications may need to be made to help reduce cost and manufacturing time. The head unit design with some easy modifications could be mass-produced using injection or polyurethane molding processes.

A. APPENDIX

A. 1. MATLAB SCRIPT FOR CALCULATING ARM DEFLECTIONS

```
% Bending Deflections of Beam with Tensioning Cable
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% geometry %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%thickness of hollow cylinder
t=1/16;

%radii
ro=.625;
ri=ro-t;

%distance of bottom of circle from string (inches)
h=6;

%distance from vertical support to string attachment (inches)
a=64;

%Arm length inches
L=72;

%Hypotenuse length
c=sqrt(h^2+a^2);

%Angle between cable and arm
theta=atan(h/a);
thetadegrees = theta*180/pi;

%cross sectional area
```

```
A=pi*(ro^2-ri^2);

%bending moment of inertia of hollow cylindrical rod
I=(pi/4)*(ro^4-ri^4);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% material properties %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%modulus of elasticity at 21 C
Esteel=28.3e6;
Ealum=10e6;
E=Ealum;

%material density lbs/in^3
psteel=.283;
palum=.098;
p=palum;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Applied Forces %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Weight of head lbs
F=20;

%Weight of bar per unit length
w0=A*p;
%Weight of bar
W=w0*L

%Force applied by tensioning line
F_T = (F*L - w0*L^2/2)/(a*sin(theta))

%Reaction Forces in Joint
Rx=F_T*cos(theta);
Ry=F+W-F_T*sin(theta);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Graphs %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
x = (0:0.01:L);
x1 = (0:0.01:a);
x2 = (a:0.01:L);

V1 = Ry-w0*x1;
V2 = Ry-w0*x2 + F_T*sin(theta);

M1 = Ry*x1-(w0/2)*x1.^2;
M2 = Ry*x2-(w0/2)*x2.^2 + F_T*sin(theta)*(x2-a);

u1 = ((Ry*x1.^3)/6 - (w0*x1.^4)/24)/(E*I);
u2 = ((Ry*x2.^3)/6 - (w0*x2.^4)/24 + (F_T*sin(theta)*(x2-a).^3)/6)/(E*I);

%figure;
%plot(x1,V1,x2,V2)
%xlabel('Distance in X (inches)')
%ylabel('Shear Force (Lbs)')
%title('Shear Diagram')

%figure;
%plot(x1,M1,x2,M2)
%xlabel('Distance in X (inches)')
```

```
%ylabel('Bending Moment(Lbs*in)')
%title('Bending Moment Diagram')

figure;
plot(x1,u1,x2,u2)
xlabel('Distance in X (inches)')
ylabel('Deflection in Y (inches)')
title('Deflection Diagram')
```

B. REFERENCES

Roy, Deb K, et al. The Human Speechome Project. July 2006. Cognitive Machines Group, MIT Media Lab. 3 May 2008. <http://www.media.mit.edu/press/speechome/speechome-cogsci.pdf>.

"Series Description." Hirose Connectors. 3 May 2008 <http://www.hirose-connectors.com/connectors/H205SeriesGaiyou.aspx?c1=LF&c3=3>.