Final Fall Report

EML 4551C – Senior Design – Fall 2012 Deliverable

Active Surface Shaping for Reflectors

Team # 9

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Introduction

The Harris Corporation is an international communications and information technology company dedicated to developing best-in-class assured communications products, systems, and services. One of the many systems they produce are mesh reflectors designed to send and receive communication signals for military and commercial applications. These mesh reflectors must first be adjusted to specific surface geometries on ground, then stowed inside of a shuttle before they are deployed in space. A typical reflector described to the team by our Harris sponsor has eight ribs stemming from its center which constitute the main structural support of the mesh material as seen in Figure 1. Along each of these ribs, there are seventeen adjustment mechanisms that are responsible for three adjustment points. In total, there are 136 adjustment mechanisms located on a reflector. For certain high frequency applications, this process becomes even more complex since the number of adjustments are greatly increased as well as the resolution of these adjustments. Achieving desired geometrical surface shape is labor intensive and time consuming due the current process which requires manual adjustments thousands of times.

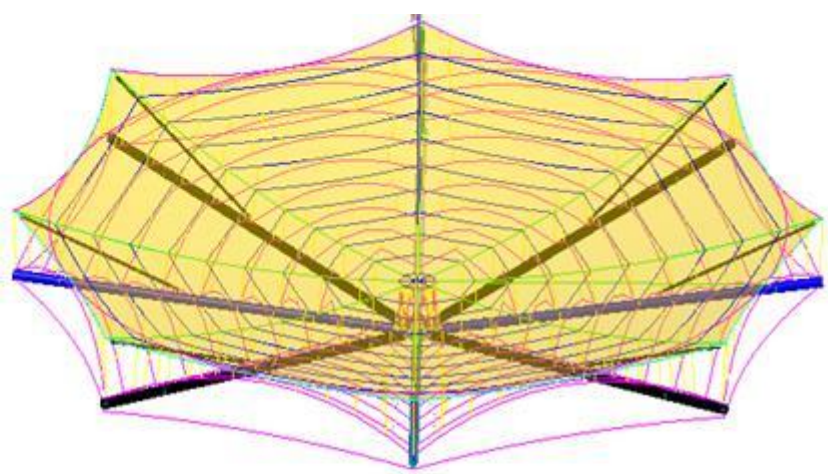


Figure 1 Eight rib reflector

Background

Figure 2 shows a two dimensional cross sectional view of the adjustment mechanism attached to the reflector. The blue represents the surface mesh of the reflector, black is the structural rib of the reflector where the mechanism is physically mounted onto, and the green lines are supportive chords. The yellow and red lines are the adjustable components of the reflector to change the surface geometry of the mesh. The yellow lines are straws that are adjusted vertically and red lines are the adjustment chords that are tightened and loosed until desired. When the adjustments are finalized, the chords are crisscrossed and bonded together, then the mechanism can be removed from the points indicated by the yellow arrows seen in Figure 4.

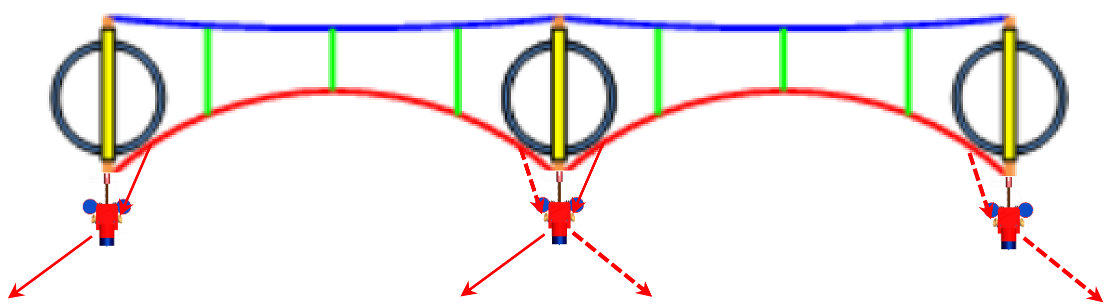


Figure 2 2D cross sectional view of adjustment mechanism configuration

A previous adjustment mechanism, shown in Figure 3, was presented to the team by the Harris sponsor that utilized an angled configuration to pull the chords. This design interfered with adjacent components when stowed away and also required many different adjusters to accommodate varying chord angles along the reflector rib. To solve this problem, Harris altered the configuration of the adjustment mechanism to a parallel pull configuration seen in Figure 4. This permitted the chord pull angle to be independent of the chord orientation, allowing for a more universal adjustment mechanism.

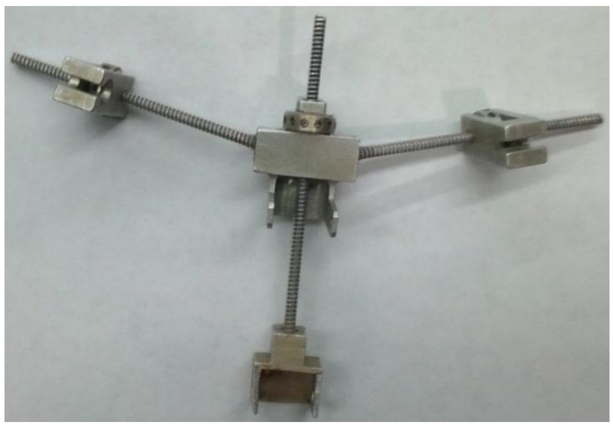


Figure 3 Previous adjustment mechanism with angled configuration

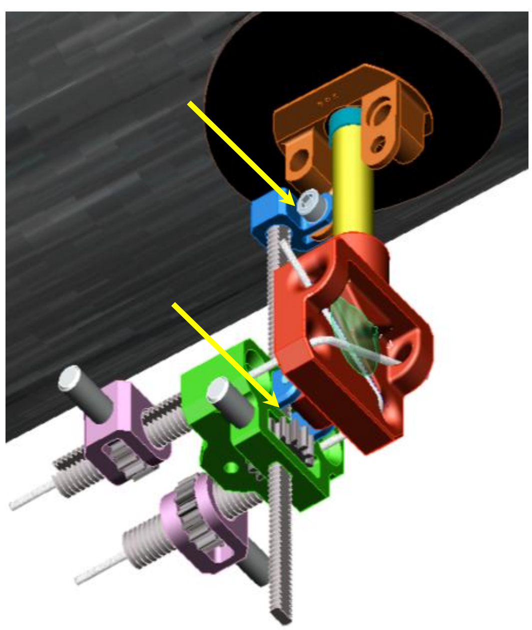


Figure 4 Adjustment mechanism with parallel pull configuration

Project Scope

The project given to team nine by Harris Corporation is to generate the necessary mechanism and control logic to make automatic hands-free adjustments of a reflector surface. With an older adjustment mechanism shown to the team, and CAD drawings provided of a current design, the team is to automate the existing parallel-pull mechanism. The primary goals are to build one high precision mechanism and construct a visual display to demonstrate that the mechanism is capable of high linear resolution as required from Harris. Given that there is a weight tolerance for additional components, hardware may be added to provide wireless capability and an integrated power supply to make the mechanism fully wireless.

Customer Needs

Given the task to build one high precision adjustment mechanism, certain constraints were given by the Harris sponsor that the mechanism must be able to perform within. The linear range for each adjustment location must be 0.100" with a linear resolution of 0.001" and lifespan of 10,000 linear inches. It is desired that each of the adjustment mechanisms be lightweight as possible, preferably under 80 grams and cost $800 per unit. The visual display should have a Linear Variable Differential Transformer (LVDT) to correspond to each adjustment chord, which measures the displacement accurately and shows this measurement on an output screen.

Material Selection

The design process of the adjustment mechanism began with redesigning the base of the mechanism with slots to house the motors. The team decided that motors directly mounted to the base would lead to less complications in the future. The finalized design seen in Figure 5 was based on CAD files provided by Harris for dimensions such as spacing between the chords and location for the mount.

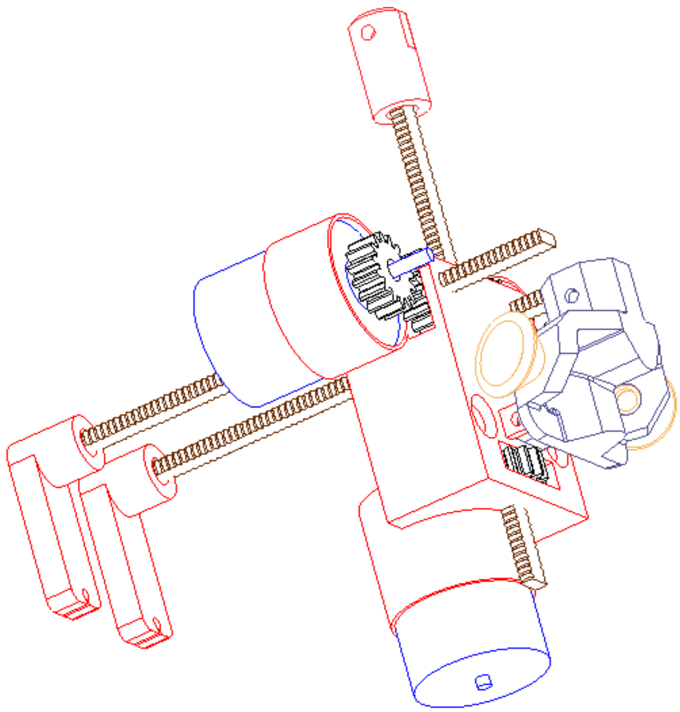


Figure 5 CAD of automated adjustment mechanism

Two materials were considered for the components of the mechanism to be potentially fabricated with: aluminum 6061 and ABS plastic from a 3D printer. Initial calculations based on the volume of material used from ProEngineer had the Al6061 base weighing 17.33g compared to ABS plastic weighing only 6.53g. The ABS plastic was selected as the primary material due to the lightweight characteristic and ability to prototype quickly from the 3D printer located on FSU's College of Engineering campus. Other components to be fabricated out of ABS plastic are the chord and straw anchors which can be seen better in Figure 7 in Appendix A, which shows an exploded view of the mechanism. The threads will be made out of aluminum to reduce wear, and the gears will be made out of Delrin for a low coefficient of friction.

Motor Selection

For this application, a high precision open control system was needed. Stepper motors rotate at specific angular increments, called steps from digital pulses, compared to conventional motors that run continuously when a voltage is applied. Therefore the use of this type of motor was the logical choice for this system because they offer precise rotation control.

In order to select a proper motor for this application, several requirements needed to be addressed namely, torque requirements and linear resolution of adjustments. Utilizing #4-40 all-thread as the heart of the mechanical adjustments, a captive geared nut creates translational movements. Using the lead of the thread and a simple proportion equation (Equation 3 in Appendix B), it is determined that a step angle of 14.4 degrees is needed to reach a .001" linear resolution. Torque requirements were calculated using two different equations which are both located in Appendix B, Equation 1 from a professor and Equation 2 was provided by the Harris sponsor. Both of these equations have empirical values, coefficient of friction and nut fitting factor, that lead to a slight degree of uncertainty. Nonetheless, both calculations yielded similar values around five milli-newton-meters, which provides a high level of confidence in their accuracy. Exploring the market as to what is available in micro-stepper motors, it was determined that the best selection would be the Faulhaber AM1524. Although this motor only outputs six milli-newton-meters of torque and has slightly poor resolution at fifteen degrees per step, it is quite affordable and very lightweight at twelve grams as compared to other micro-steppers on the market. To achieve greater linear resolution and increase the torque output of the motor to allow for a margin for any additional frictional losses in the system, there will be a 2:1 gear reduction.

Electrical Components

To automate the control of the reflector surface adjustment mechanism, certain electrical components need to be integrated into the assembly. The mechanism that is currently used by Harris has three individual points that can be adjusted, two for the opposing chords and one for the vertical straw. For each of these points, a micro stepper motor is to be employed to allow the ability to actuate the respective chord remotely.

A microcontroller is the main and most essential electrical component to be used to handle various tasks for this project. The selected microcontroller to be utilized by this project is the Arduino Nano due to its lightweight attribute of only nine grams and open source platform. The advantage of the Arduino environment is that it allows electronic prototyping that is flexible and easy to use with a widespread development community. The language requirements to program an Arduino based system is in C/C++, which all members of the group have familiarity with, instead of having to learn a brand new programming language.

Motors are the next important components to actually perform the physical movement at the adjustment points. The type of motor selected are stepper motors to ensure that there is accurate displacement as discussed earlier. On the Arduino microcontroller, the pins can only provide a maximum output current of 40mA, when the necessary current to drive our Faulhaber stepper motor is 150mA. If the motor wires were to be directly connected to the microcontroller, the outputs could potentially get damaged. Also, a stepper motor is not like a common DC motor that will spin when a current is applied. The current has to be applied in a sequence across the four motor wires, along with the polarity to provide direction of the spin. A solution to these problems are to use a H-Bridge motor driver, which provides more available drive current for the stepper and ability to switch current drive polarity. There were two motor driver chips under consideration, the Texas Instrument SN754410 and SGS-Thomson L293D that were similarly priced at ~$3. Both have the same pin layout, so they are easily interchangeable with each other without any hardware or code changes. Also, both have a built in flyback diodes to protect the driver that minimize inductive voltage spikes when the current changed too quickly. The only difference is that the SN754410 can provide a current of 1A compared to the 0.6A from the L293D. For the scope of this project, either motor drive can be used, but the SN754410 was selected due higher current output and availability from professor. The L293D can be used as a backup if the SN754410 does not function as intended. With the addition of an H-Bridge, the lifespan of the Arduino microcontroller will be increased with protection from voltage spikes.

For the testing phase of the electrical components, the Arduino Nano, motor driver, and motors will be put onto a breadboard to be programmed. To attempt to keep the weight as low as possible and to reduce the number of required inputs and outputs on the Arduino board, only one motor driver will be used. Three transistors will be used to switch electrical signals between each stepper motor. Once the programming and electrical setup are finalized on the breadboard, the circuit will be transferred to a printed circuit board (PCB) and the components will be soldered on in order to further reduce the weight. With these components, only seven pins will be used out of the thirteen available on the Nano which will leave four pins for Wi-Fi to be implemented once the system is functioning properly.

The primary goal is to get the motors connected to the microcontroller then be able to control them remotely. Secondary goals are to implement wireless capability and have an integrated power supply given that there is an allowable tolerance for the extra weight. An Arduino Wi-Fi Shield may be connected to the Arduino Nano to give the mechanism a wireless connectivity that can connect to a standard 802.11b/g wireless network. If the mechanism is still lightweight enough, an integrated power supply may be added to make the system completely wireless. A lithium ion polymer battery is under consideration due to its ability to recharge, low-cost, and it high energy density (power to weight ratio).

Visual Demonstration Setup

To demonstrate the designed adjustment mechanism, a table-top visual will be constructed as seen in Figure 6. The visual setup will consist of a fully-functioning automated adjustment mechanism, housed in an 80/20 structural aluminum stand. Adjustments of the chords and straw will be monitored via a LVDT at each adjustment and the linear distance will be output onto the computer via software such as LabView. This will allow for demonstration of linear resolution and repeatability of the adjustments being made. An exploded view of the demonstration setup can be seen in Figure 8 in Appendix A.

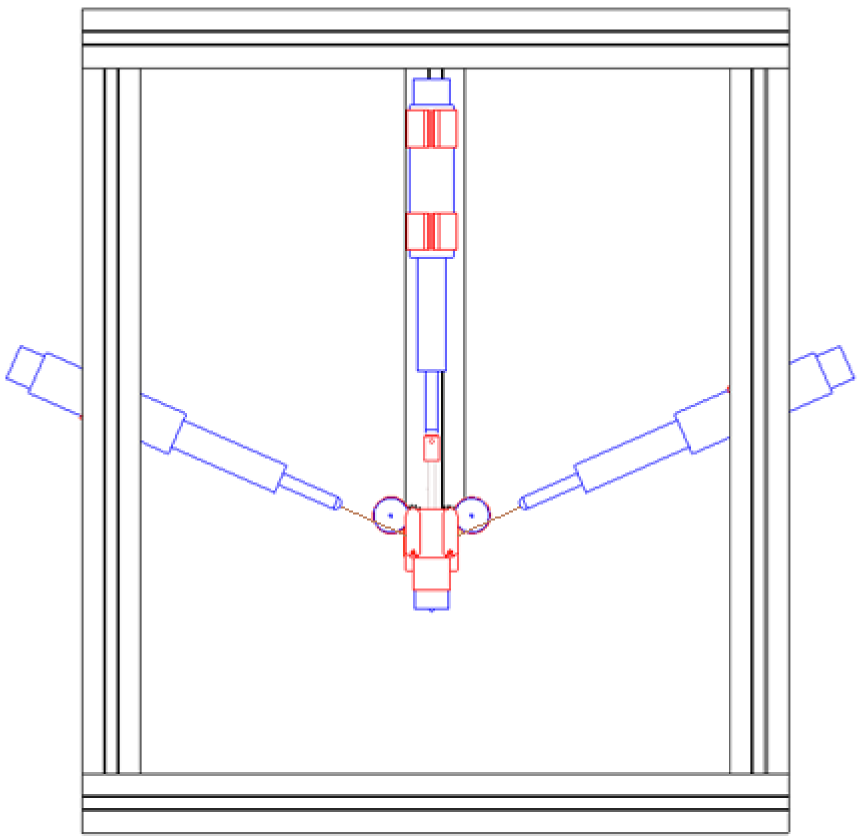


Figure 6 CAD of visual display setup

Conclusion

The project given to team nine by Harris Corporation is to generate the necessary mechanism and control logic to make automatic hands-free adjustments of a reflector surface. The current process is very time consuming and requires the adjustment of thousands of points multiple times manually until the desired surface geometry of the reflector is achieved. The primary goals are to build one high precision mechanism and construct a visual display to demonstrate that the mechanism is capable of high linear resolution as required from Harris. This will be done by employing three stepper motors at each of the adjustment locations which will be controlled with a microcontroller remotely. Given that there is a weight tolerance for additional components, hardware may be added to provide wireless capability along with an integrated power supply to make the mechanism fully wireless.

For the visual demonstration, a structural frame made out of 80-20 aluminum will be constructed to house the mechanism. With the mechanism mounted to the structure, spring loaded LVDTs will be mounted on the structure to measure displacement corresponding to each individual chord. Displacement readings from the LVDTs will be output to a computer screen due to the miniscule adjustments that may be hard to see with the human eye.

By finalizing the stationary motor design within the constraints specified by Harris, the ordering process of the components has begun with the approval of the Harris sponsor and faculty advisors. This is to ensure that the components will be available when the spring semester begins and allows construction and programming to begin as soon as possible. The 3D printer on campus will be able to prototype the base of the mechanism in a few days. The most essential components of this project to be ordered are the motors, which can take up to 6-8 weeks to manufacture and ship if not in stock. All electrical components are readily available from various vendors. Future tasks to be accomplished by the team include a tour of the Harris Corporation facilities in Melbourne, FL, build-up of prototype, programming/debugging, and initial testing as seen in the Gantt chart located in the Appendix C.

References

"Arduino - ArduinoBoardNano." *Arduino - ArduinoBoardNano*. N.p., n.d. Web. 10 Dec. 2012. <http://arduino.cc/en/Main/ArduinoBoardNano>.

"Civilian Government Managing One of the World's Most Reliable Communications Networks." *Harris Corporation*. N.p., n.d. Web. 10 Dec. 2012. <http://harris.com/>.

"Leading Manufacturer of Small Precision Mechanical Components." *Precision Mechanical Components Timing Belts Pulleys Spur Gears Couplings Bearings Sprockets Retaining Rings Brakes Helical Gears Clutches Universal Joints*. N.p., n.d. Web. 10 Dec. 2012.

"Product Index Integrated Circuits (ICs) PMIC - MOSFET, Bridge Drivers - External Switch SN754410NE." *SN754410NE Texas Instruments*. N.p., n.d. Web. 10 Dec. 2012.

"Rush Gears Inc." *Rush Gears Inc*. N.p., n.d. Web. 10 Dec. 2012. <http://www.rushgears.com/>.

Faulhaber. *Stepper Motors 6.0mNm*. N.p.: Faulhaber, n.d. *Micromo*. Web. 10 Dec. 2012. <http://www.faulhaber.com/uploadpk/EN_AM1524_PCS.pdf>.

Jordan, Akeem. "Team 9 - Harris Active Reflector Surface Shaping." *Team 9 - Harris Active Reflector Surface Shaping*. FSU CoE, n.d. Web. 10 Dec. 2012. <http://eng.fsu.edu/me/senior_design/2013/team9/>.

Appendix A – Additional Pictures

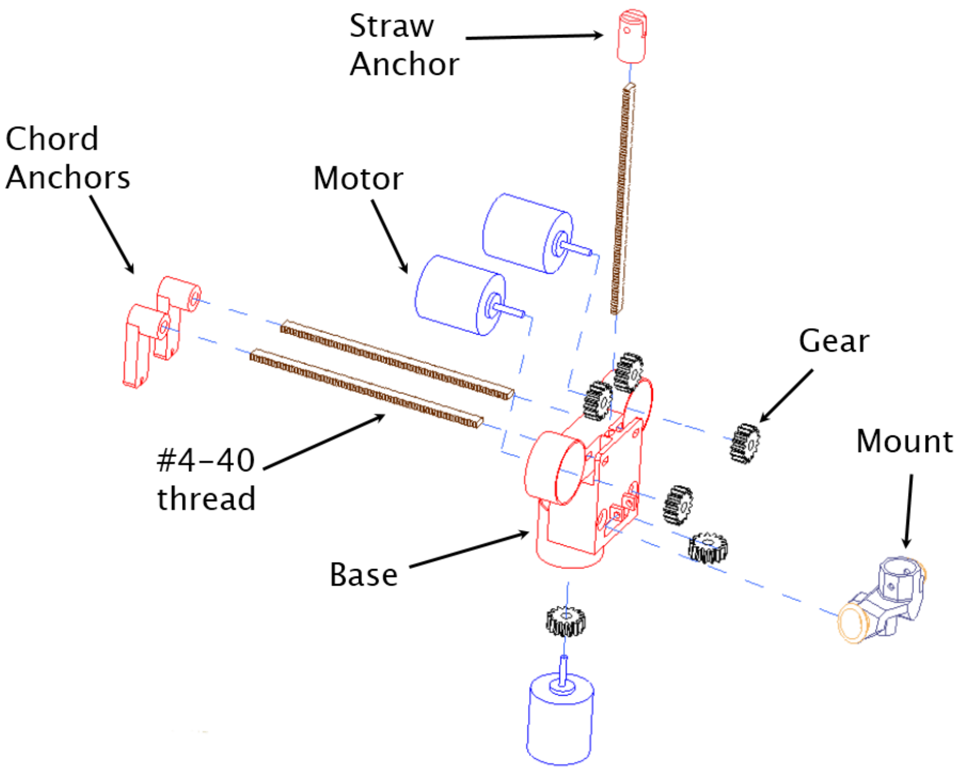


Figure 7 Exploded view of adjustment mechanism

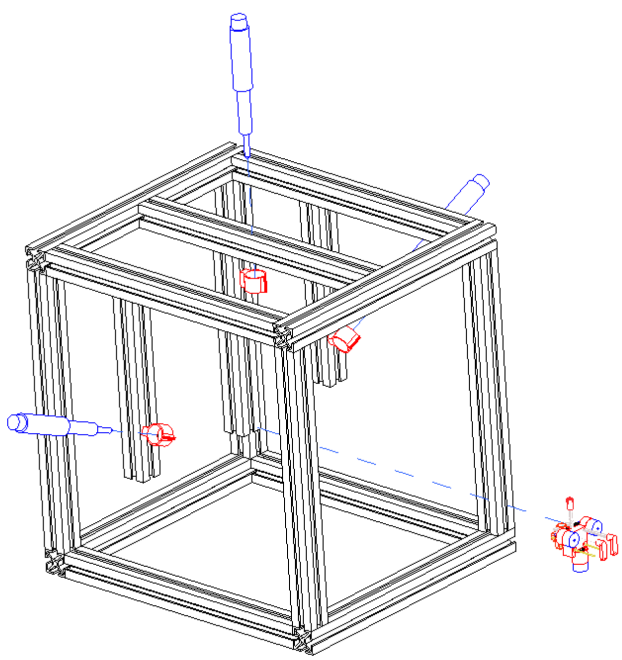


Figure 8 Exploded view of visual demonstration setup

Appendix B – Equations

Torque Calculations

$$T_{raise} = \frac{\mathrm{F}d_m}{2}\left(\frac{l + \pi\mu d_m}{\pi d_m - \mu l}\right) = .0374 \text{ in} * \text{lbf} = 4.23 \text{ mN} * \text{m}$$

Equation 1

F = required pull force = 2 lbf

d_m = mean diameter = 0.095 in

μ = coefficient of friction = 0.3

l = lead = # of Starts * Pitch = 0.025 in

Pitch = 1/threads per inch = 0.025 in

$$\mathrm{T} = \mathrm{kFd} = .0448 \text{ in} * \text{lb} = 5.06 \text{ mN} * \text{m}$$

Equation 2

k = fitting factor = 0.2

F = required pull force = 2 lbf

d = diameter = 0.112 in

Gear Calculations

Required step angle from motor to obtain 0.001” resolution:

$$\frac{0.025\ in}{360\ deg} = \frac{0.001\ in}{x} \Rightarrow x = 14.4°$$

Equation 3

Actual step from Faulhaber AM1524 motor:

$$\frac{0.025\ in}{360°} = \frac{x}{15°} \Rightarrow x = 0.00104\ in \text{ Linear resolution}$$

Equation 4

Using 2:1 gear ratio:

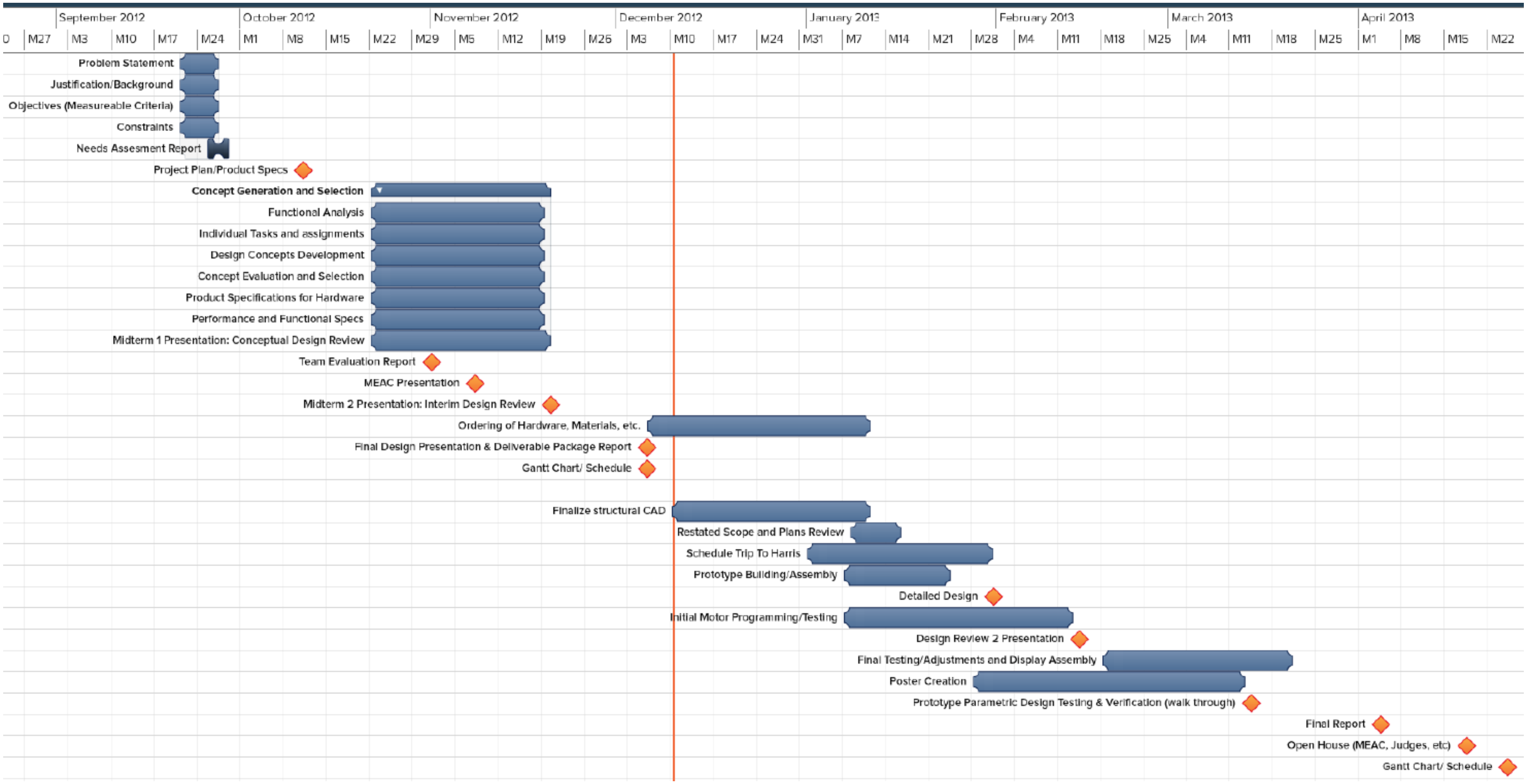
$$\frac{0.025''}{360°} = \frac{x}{7.5°} \Rightarrow x = 0.000521 in \text{ Linear resolution}$$

Equation 5

Appendix C - Tables

Component	Purpose	Weight	Cost
Assembly			
Arduino Nano	Microcontroller	6g	42.79
Arduino Wi-Fi Shield	Wireless Control	36g	83.99
SGS - Thomson L293D	Motor Driver	0.99g	3.50
Al6061 Body	Assembly body	23.42g	N/A
ABS plastic body	Assembly body	12.6g	N/A
Faulhaber AM1524 Motor x 3	Stepper motor	36g	360
400mAh Lithium polymer ion	Integrated power supply	9g	7.95
Total with Nano, Wi-Fi, Battery			**$500**
Al6061 body **ABS body**		**115.41g** **100.5g**	

Gantt Chart


September 2012
October 2012
November 2012
December 2012
January 2013
February 2013
March 2013
April 2013
Problem Statement
Justification/Background
Objectives (Measureable Criteria)
Constraints
Needs Assesment Report
Project Plan/Product Specs
Concept Generation and Selection
Functional Analysis
Individual Tasks and assignments
Design Concepts Development
Concept Evaluation and Selection
Product Specifications for Hardware
Performance and Functional Specs
Midterm 1 Presentation: Conceptual Design Review
Team Evaluation Report
MEAC Presentation
Midterm 2 Presentation: Interim Design Review
Ordering of Hardware, Materials, etc.
Final Design Presentation & Deliverable Package Report
Gantt Chart/ Schedule
Finalize structural CAD
Restated Scope and Plans Review
Schedule Trip To Harris
Prototype Building/Assembly
Detailed Design
Initial Motor Programming/Testing
Design Review 2 Presentation
Final Testing/Adjustments and Display Assembly
Poster Creation
Prototype Parametric Design Testing & Verification (walk through)
Final Report
Open House (MEAC, Judges, etc)
Gantt Chart/ Schedule