Automated Telescope

<u>EECS 129B Winter 2008 Final Project Report</u>

Team Members

Name of Student	Email
Louis Chow	lchow@uci.edu
Jesse Liang	jliang3@uci.edu
Philip Pham	philipp@uci.edu

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1. Abstract

The goal of this project is to implement automation to a classic telescope. A user will be able to vary the rotation of the pitch and yaw of the telescope using a computer as a console. The telescope will be able to enter two modes of input; manual control, and automatic control. The manual control option will allow the user to move the telescope using the controls W (increase yaw), S (decrease yaw), A (rotate pitch to the left), and D (rotate pitch to the right). In its automatic control option, the telescope take in user input and send it to the micro controller allowing the telescope to observe specific points of interest without having to be manually adjusted. It will accept integers (in degrees) and will automatically move to the respective input when commanded.

2. Project Overview (High level)

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                    ┌──────────────┐      ┌──────────────┐      ┌──────────────┐
              ┌────▶│ X-Axis Servo │─────▶│ 5:1 Gear Box │─────▶│  Telescope   │
              │     └──────┬───────┘      └──────────────┘      │    X-Axis    │
              │            │▲                                    └──────────────┘
              │            ▼│
  ┌───────────┴──┐      ┌──────────────┐      ┌──────────────┐
  │  Position    │─────▶│   Arduino    │─────▶│   Lapatop    │
  │   Senor      │◀──   │              │◀─────│  (Control    │
  └──────────────┘      └──────┬───────┘      │  Interface)  │
              ▲                │▲              └──────────────┘
              │                ▼│
              │     ┌──────────────┐      ┌──────────────┐      ┌──────────────┐
              └─────│ Y-Axis Servo │─────▶│ 5:1 Gear Box │─────▶│  Telescope   │
                    └──────────────┘      └──────────────┘      │    Y-Axis    │
                                                                 └──────────────┘
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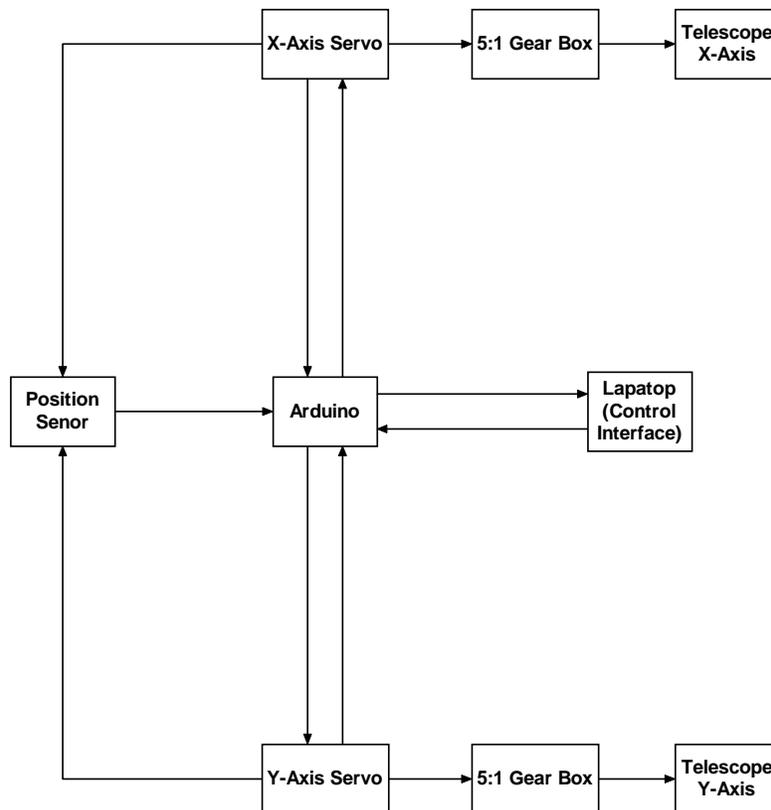
3. Project Components

- Mechanical - Design and Construction of the Telescope
  - Woodwork
  - Metalwork
  - Gears

- Electrical - Design and Construction of Printed Circuit Boards
  - Circuit Diagrams
  - Circuit Etching
  - Arduino Implementation
  - Encoder Implementation
  - Stepper Motor Implementation

- Software - Coding of the Microcontroller and Console
  - Arduino Microcontroller Code
  - Computer Console Code
  - Encoder Implementation
  - Stepper Motor Implementation

4. Design Description

A. Mechanical

The main portion or the mechanical engineering aspect of the project is the actual construction of the telescope and the turret that it is mounted on. A step by step tutorial on how to build a simple telescope and base can be found at http://pages.sbcglobal.net/raycash/manualv2.pdf.

The telescope is made using 2 mirrors, an objective mirror, our primary mirror, and a diagonal flat mirror, our secondary mirror. The objective mirror is placed at the end of A 3 foot cardboard tube (sonotube). The diagonal mirror is placed inside the tube near the front end, and is adjusted to a 45 degree angle in order to deflect light into an eye piece.

The size of the diagonal mirror is proportional to the objective mirror. Its formula is:

d = df + ((D - df)/F) x Lde

d = minor axis of the diagonal

df = focal length of the objective mirror multiplied by the result of the fully illumi-nated field desired, divided by 57.3 radians.
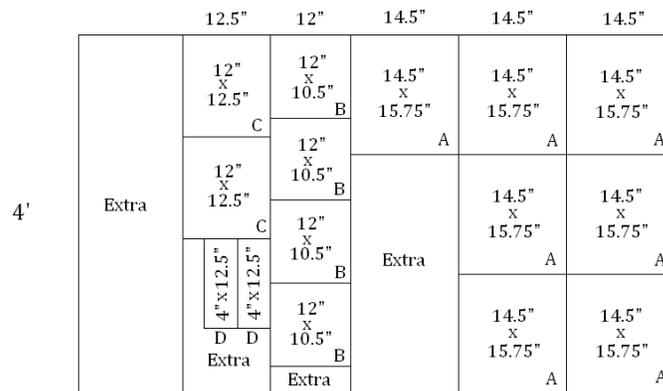
D = the diameter of the objective mirror

Lde = the distance between the diagonal and the field stop of the eyepiece

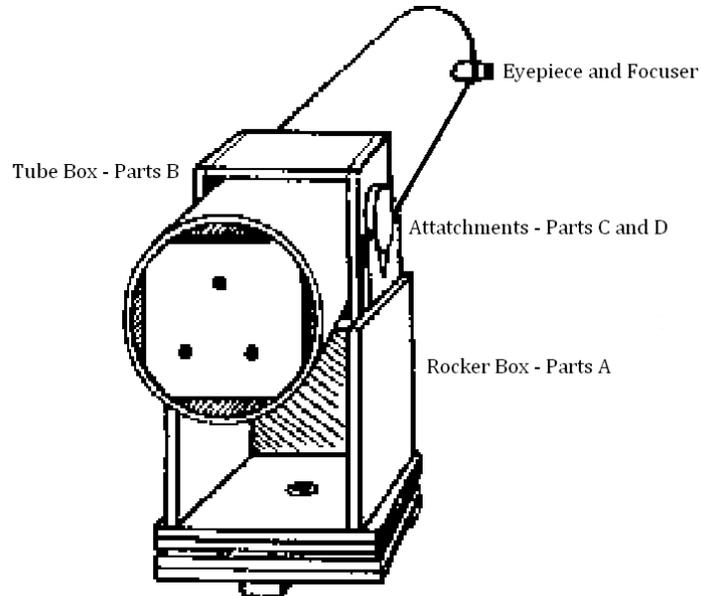The length of the tube is represented by:

Focal Ratio x Mirror Diameter

The focal ratio is given measurement of the objective mirror. Although it is given, its accuracy may not be precise and minor adjustments in positioning needs to be made.

The base is constructed from a 0.5 inch thick, 4 by 8 feet piece of wood.

|	12.5"	12"	14.5"	14.5"	14.5"
		12" X 12.5" C	12" X 10.5" B	14.5" X 15.75" A	14.5" X 15.75" A	14.5" X 15.75" A
4'	Extra	12" X 12.5" C	12" X 10.5" B	Extra	14.5" X 15.75" A	14.5" X 15.75" A
		4"x12.5" D 4"x12.5" D Extra	12" X 10.5" B 12" X 10.5" B Extra		14.5" X 15.75" A	14.5" X 15.75" A

8'

Figure 1

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Figure 2

After cutting the wood, to its respective size, parts A is constructed into a box with an open side, leaving room for electrical work. Parts B constructed into a cube shape, where it will house the sonotube. On the sides of parts B are 2 lazy susans, attached to parts D, allowing the telescope to move in a vertical angle. Parts B and C are then attached to parts A by drilling the opposite end of parts D. Figure 2 is borrowed from the tutorial with our respective deviations.

On the bottom of part A, a hole was drilled in the center of the bottom to piece to mount the shaft and gear that will rotate the telescope horizontally. To turn it vertically, we use a worm gear for its strength and precision. On one side of part B, another hole was also drilled through to make room for the shaft and gear that will turn it vertically. A shaft containing the motor and worm gear are attached using two pieces of wood and mounting them in respect to the gear coming out of part B.
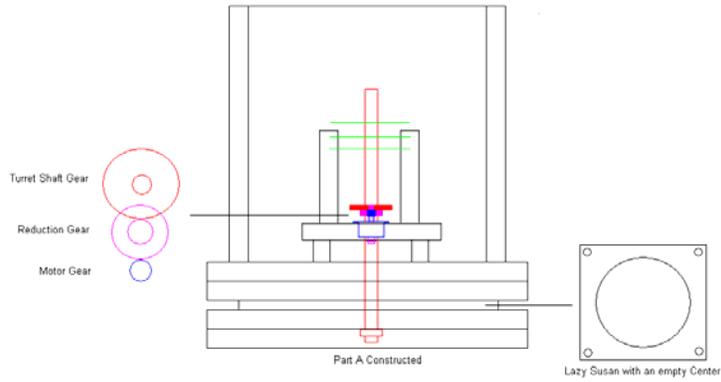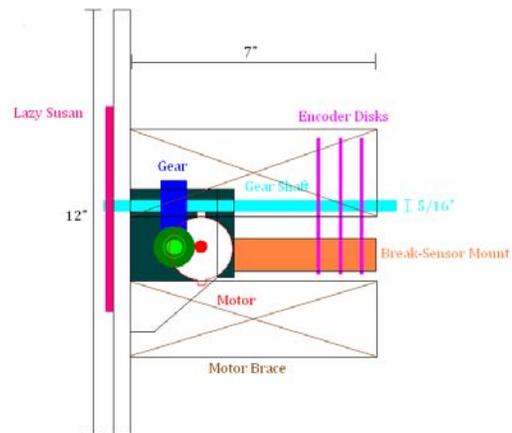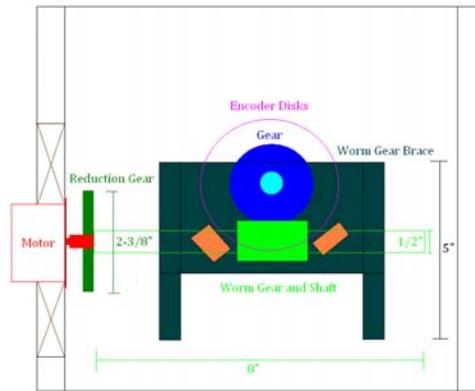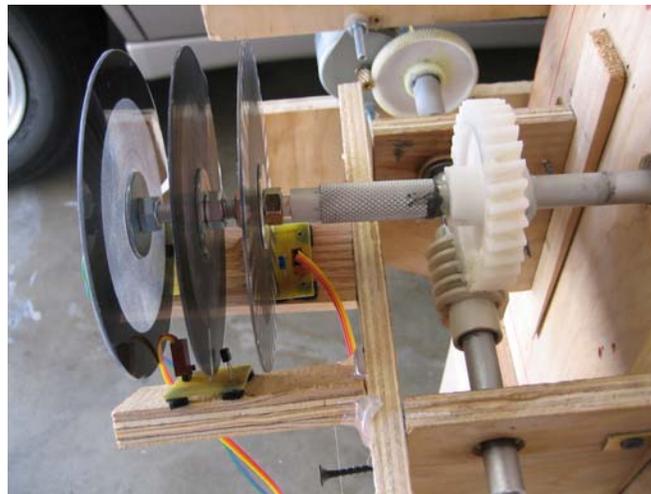
Side View of Part A
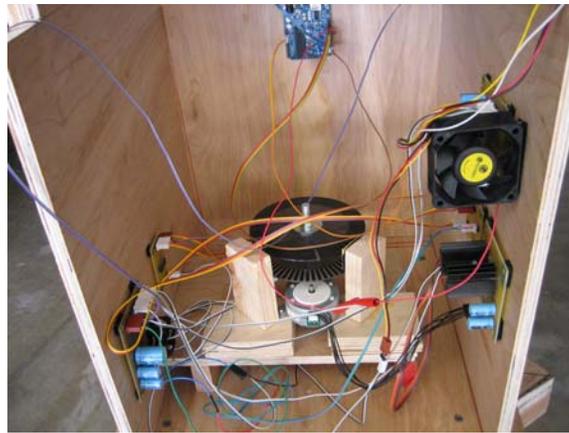
Part A Complete

All shafts were made using a turning lathe. They all have a 1/2" diameter, with American fine threaded ends of 5/16" diamters.

Side View of Part B

Front View of Part B

Part B Top View

We used a strong epoxy to station the gear as shown in the side view of part B. This was given enough clearance for the worm gear and its reduction gear shown by the green circles. The most important measurement was the distance between the gear and the wood parallel to it. We measured it to be 2-3/8" and drilled a 1/2" diameter hole into small wooden boards which would hold the worm gear and its shaft. The simple measurement ensures contact between the worm gear, and the main gear that allows vertical rotation. The length of each shaft varied, but was made long enough for its purpose. The brackets were adjusted to take into account their lengths before permanently mounted.

Both gears of rotation are accompanied by a white plastic gear, which ultimately changes the ratio between the gear attached to the motor and the gear mounted to the

bases. The deviation of the ratio allows a reduction in turning the gear, which lessens the stress on the motor gear by increasing the torque. This heavily improves our design as the telescope must fight against gravity while turning in the vertical direction.

For both parts A and B, the encoders were attached through a 5/16" fine threaded extension of the shaft using the respective size nuts. This allowed us to properly adjust the distance between each disk. The break-beam sensors were then mounted to a small block of wood that was glued onto the small board holding together the worm gear braces.


Telescope Side View

Telescope Front View

B. Electrical

We created separate PCB's for each component of our telescope. Using EagleCAD, we designed and hand routed our circuits, and printed the gerber onto an adhesive paper. The image is printed backwards, so when applied, it is facing the correct direction. The adhesive paper was essential because our PCB's use both the top and bottom layers of the copper clad silicon board.
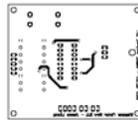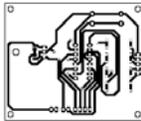

Gerber Images – 8.5" x 11"

We began by thoroughly cleaning the copper boards, which will later allow the ink from the gerber printings to transfer onto it. After applying the gerber diagrams onto the copper clad boards. We slowly ironed over the boards and peeled off the paper, transferring the gerber layout onto the copper clad boards.

We then proceeded to dip the boards into hydrochloric acid which will strip away excess copper, leaving the copper circuit behind.
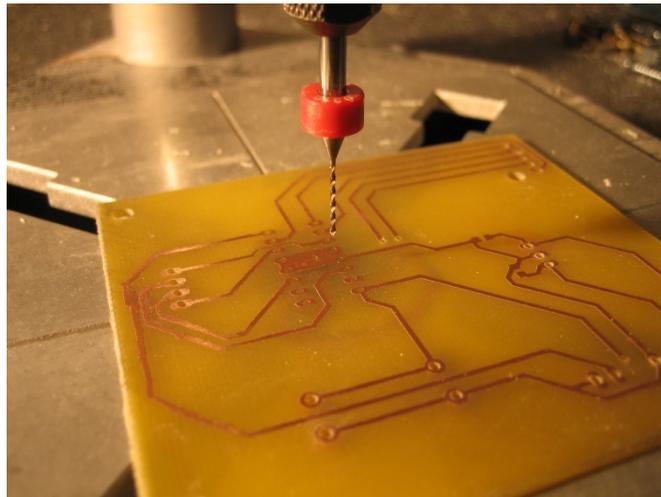
Hydrochloric Acid Solution with Bubbler
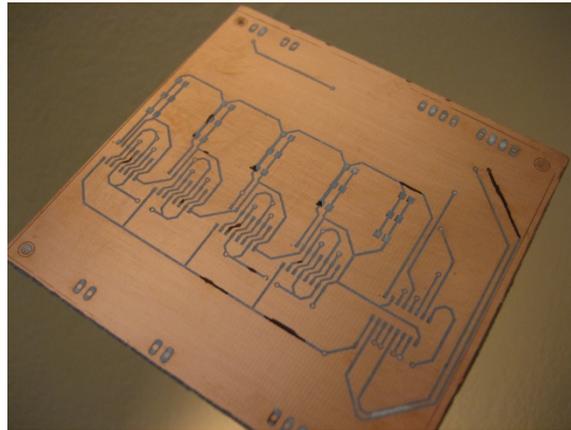
Circuit Before Dipping in Hydrochloric Acid

Using a small drill press, we drilled via-holes, which made soldering through both sides of the board a lot easier. We use 0805 sized service mounts, which are small, yet large enough for us to solder with the naked eye.

Drill Press


Board after Drilling and Etching

SMD Resistor Chips – "monty N5ESE"

For our power boards we added bypass capacitors which prevents voltage dips when powering on the motors. They also help filter out unwanted noise. For mounting purposes, we used velcro tape. This made mounting a lot quicker and easier than drilling holes and applying mounting screws. This also prevents the boards from cracking while traditionally drilling mounting holes. Due to the limited amount of pins from the Arduino board, we created a motor selector, allowing us to use only one Arduino. For the motor drivers, the voltage regulators were reaching over 200°F. To resolve this issue, we added heat sinks and fans to cool off the temperature. For our encoders, we used a Schmitt trigger, which generated an ideal 0 - 5V digital signal.
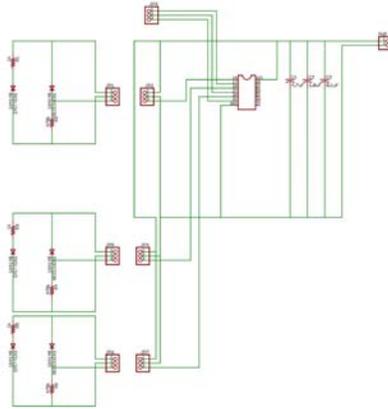
Encoder Circuit
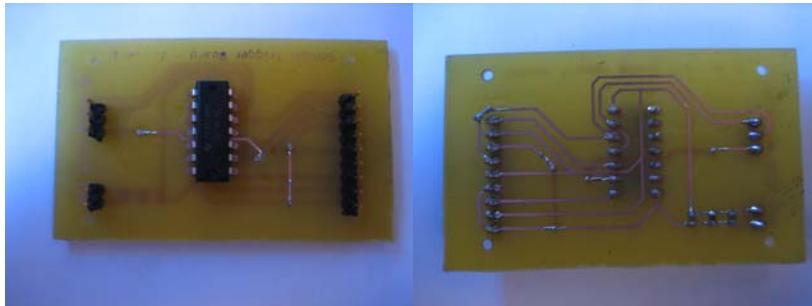
Encoder Top and Bottom
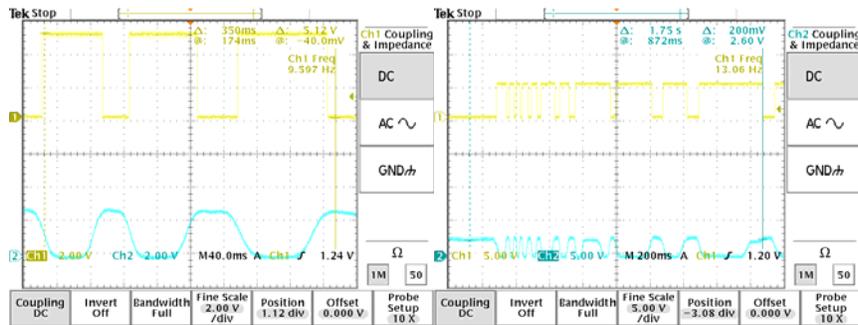
Encoder Waveforms
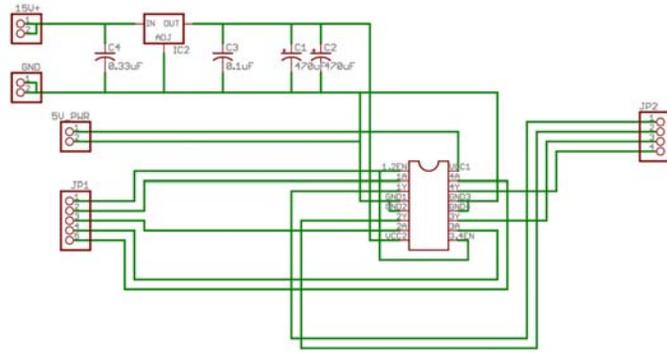
Motor Driver Circuit

Horizontal and Vertical Motor Drivers
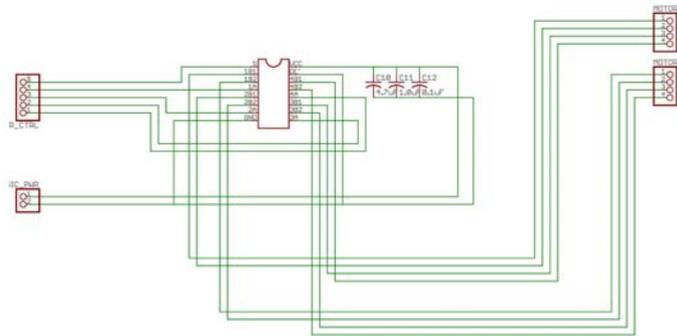
Motor Selector Circuit
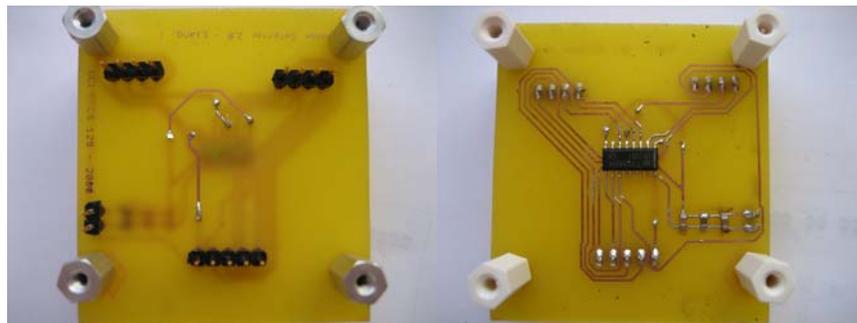
Motor Selector Top and Bottom

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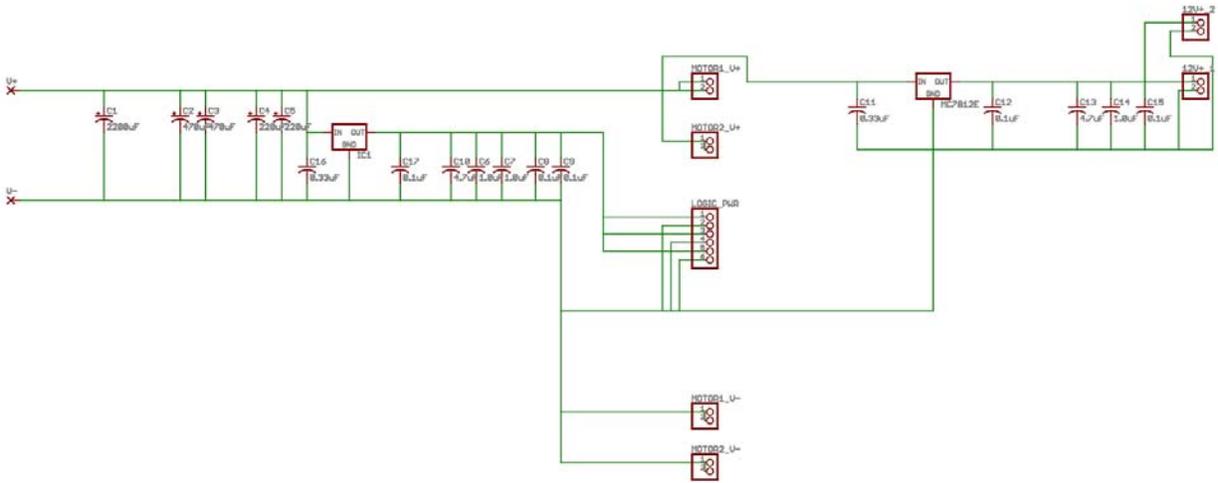
Power Distributer Circuit
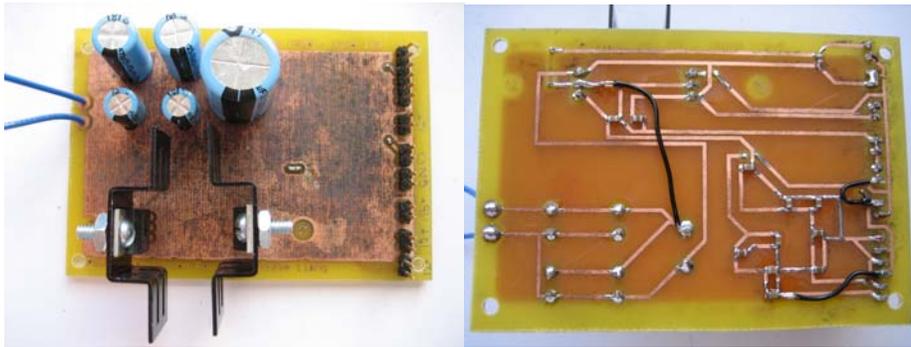
Power Distributer Top and Bottom

To add precision to the telescope, we used encoders. The use of encoders allows us to measure, in degrees, how much the telescope will turn vertically and horizontally. The encoder is constructed using a disk with alternating areas of printed black and clear.

Encoder Disk

Each black and clear area signifies the amount in degrees in which the telescope has

moved. To read this information, we used a break-beam sensor, which can give high or low values depending on what area is between the sensors.
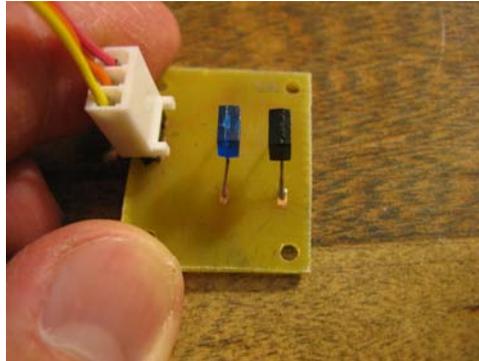
Break-beam Sensor

The disk is held between the sensors as shown in the picture, and gives a low value when the beam is block by a black pattern. When the disk is rotated to a clear area, the beam is able to pass beyond the disk allowing the other end to read a signal, which then gives us a high value. From the alternating black and clear patterns, we are able to implement a counter in our code.

All together we used 5 encoders, 2 of which are for the horizontal direction and another 3 for the vertical direction. For each of the directions we had 1 disk which was printed black except for a single area. This allowed us to create default values for the telescope to begin rotating at.

C. Software

The console which controls the microcontroller runs on a laptop. We used the Putty software to connect to the Arduino as a telnet client. From there our program would allow us to choose from three options; free, coordinate, and moon mode. The purpose of moon mode was to enable the telescope to automatically track the moon, however, after analyzing the algorithm to do so, countless variables and arrays were needed, and we were unable to fit them all into the Arduino's memory.

We designed the manual controls (free mode) to use W to move the telescope up, S to move down, A to rotate left, and D to rotate right; the traditional outline for first person

shooting games. The controls require the user to hold down the key. This sends a constant input to the Arduino, and would leave the telescope to move however many commands were input. The problem with this is, the user might not know how many times the command had been entered, and may have to wait until it is finished before moving in the next direction. To compensate, we applied a small buffer, and a break statement that would allow the program to stop moving in the current direction if the next input is different. This prevents the Arduino to be overflowed with commands.

In automatic mode, the user enters a measurement of degrees to move horizontally and vertically. The telescope will automatically move to the correct position by using a counter implemented by the encoder. To compensate movement beyond the flexibility of the telescope, when initially powered, the telescope will move to the default position provided by the second set of encoder disks.
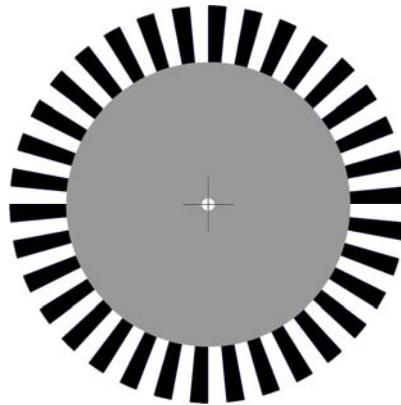
Encoder Disk
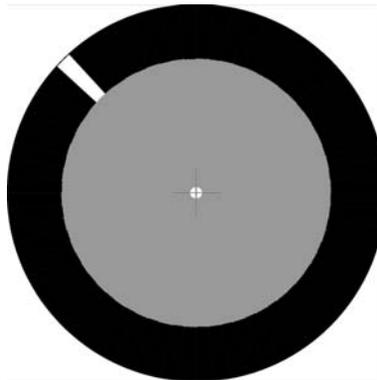
Encoder Disk with Default Position

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5. System Test Plan

Test Number	Description of Set-up	Input or Stimulus	Expected Behavior
1	Press one on console to enter free mode in order to use the WASD to control the telescope	Console – 1	Enter free mode
2	Using the console, rotate the telescope 360°	Free Mode – A	Telescope will rotate 360°
3	Using the console, rotate the telescope -360°	Free Mode – D	Telescope will rotate -360°
4	Using the console, rotate the telescope at an ambiguous degree and affirm that telescope stops when no longer commanding	Free Mode – A & D	Telescope will stop when no longer commanded to move.
5	Using the console, move the yaw of the telescope from 0° up to 60°	Free Mode – W	Telescope yaw will move up 60°
6	Using the console, move the yaw of the telescope from 60° up to 0°	Free Mode – S	Telescope yaw will move down 60°
7	Using the console, change the yaw of the telescope at an ambiguous degree and affirm that telescope stops when no longer commanding	Free Mode – W & S	Telescope will stop when no longer commanded to move.
8	Press x to exit Free Mode	Free Mode – X	Return to Console
9	Press 2 in the console to enter automatic mode.	Console – 2	Enter Automatic Mode
10	Insert ambiguous values into the console.	Degree Input	Telescope will move in respect to the values given.

Test Number	Description of Set-up	Input or Stimulus	Expected Behavior
11	Insert maximum input values possible.	Degree Input	Telescope will move in respect to the values given.
12	Insert minimum input values possible.	Degree Input	Telescope will move in respect to the values given.
13	Press x to exit Free Mode	Automatic Mode – X	Return to Console
14	In console, press 3 for Moon Mode	Console – 3	Enter Moon Mode
15	In moon mode telescope will automatically track the moon given current position.	Enter current position	Observe that the telescope is tracking the moon.
16	Voltage Measurement of all voltage rails 12V, 5V - idle	System waiting for user input	11.99V, 4.99V
17	Voltage Measurement of all voltage rails 12V, 5V - during loading	System performing a function (moving)	11.92V, 4.93V
18	Input current measurement - idle	System waiting for user input	0.1A
19	Input current measurement – during loading	System performing a function (moving)	1.2A
20	Power Consumption – during load	System performing a function (moving)	13W
21	Maximum Resolving Precision (X-Axis)	Rotate turret by the smallest step	Turret has a finite rotation resolution
22	Maximum Resolving Precision (Y-Axis)	Tilt turret by the smallest step	Turret has a finite tilt resolution
23	Temperature measurement		Some parts of the system will be hot

Test Number	Description of Set-up	Input or Stimulus	Expected Behavior
24	Rate of turn	System at max. and min. speed	Different movement speeds
25	Earth rotation compensation	Nothing	Target remains stationary in the field of view
26	Slop	Rotate / Title Turret	Alignment lost

6. Project timeline

January 12, 2008 – finish construction of base

February 1, 2008 – installed horizontal axis gear and enabled movement, implemented horizontal movement code

February 8, 2008 – constructed top telescope base

February 15, 2008 – manufactured PCB for power and movement circuitry

February 22, 2008 – Designed and tested encoder, remanufactured shafts

February 29, 2008 – Mounted Part A to Part B; Added encoders; Testing

March 3, 2008 – Made necessary adjustments of precision, mounted all PCB's, finalized code

7. Division of work

<Louis Chow>

Metal work, wood work, paperwork, motor

<Philip Pham>

Encoder installation, Coding

<Jesse Liang>

Circuit design, Circuit etching, encoder, parts construction, prototyping, R&D

8. Cost

Bill of Materials (Electronics)							
Mouser Part #	Manufacturer	mfr. Part #	Description	Packaging	Qty	Cost p. u.	Total
595-SN754410NE	Texas Instruments	SN754410	TI Quad H-Bridge	PDIP-16	1	$1.87	$1.87
511-LD1084V12	ST Microelectronics	LD1084V12	12V 5.0A Low-Dropout Regulator	TO-220	2	$1.74	$3.48
512-MC7812ECT	Fairchild Semiconductor	MC7812ECT	Linear Regulator 12V 1.0A	TO-220	1	$0.37	$0.37
512-MC7805ECT	Fairchild Semiconductor	MC7805ECT	Linear Regulator 5V 1.0A	TO-220	1	$0.37	$0.37
511-ULN2065B	ST Microelectronics	ULN2065B	1.5A Darlington Quad Array	PDIP-16	1	$1.99	$1.99
810-C2012X7R1C334K	TDK	C2012X7R1C334K	SMD 16V 0.33uF X7R Cap	SMD 0805	4	$0.32	$1.28
81-GRM40X104K25K	Murata	GRM40X104K25K	SMD 25V 0.1uF X7R Cap	SMD 0805	8	$0.13	$1.04
81-GRM219R71E105KA8D	Murata	GRM219R71E105KA8D	SMD 25V 1.0uF X7R Cap	SMD 0805	5	$0.04	$0.20
81-GRM21BR61E475KA12	Murata	GRM21BR61E475KA12	SMD 25V 4.7uF X7R Cap	SMD 0805	4	$0.40	$1.60
140-XRL25V470-RC-TB	Xicon	140-XRL25V470-RC-TB	25V 470uF 20% Electrolytic Cap	Radial	6	$0.17	$1.02
140-XRL25V2200-RC	Xicon	140-XRL25V2200-RC	25V 2200uF 20% Electrolytic Cap	Radial	1	$0.67	$0.67
140-XRL25V220-RC	Xicon	140-XRL25V220-RC	25V 220uF 20% Electrolytic Cap	Radial	2	$0.12	$0.24
707-411615B25	Comair Rotron	411615B02500	TO-220 Aluminum Heatsink (large)	Through-Hole	2	$1.38	$2.76
707-822802B00	Comair Rotron	822802B00000	TO-220 Aluminum Heatsink (small)	Through-Hole	2	$0.38	$0.76
595-CD74HC14E	Texas Instruments	CD74HC14E	Hex Inverter	PDIP-14	2	$0.64	$1.28
782-TEKT5400S	Vishay	TEK5400S	Infrared Detecting Diode	Through-Hole	5	$0.58	$2.90
782-TSKS5400S	Vishay	TSKS5400S-ASZ	Infrared Emitting Diode	Through-Hole	5	$0.54	$2.70
292-470K-RC	Xicon	292-470K-RC	SMD 470k 1% Resistor	SMD 0805	5	$0.04	$0.20
71-CRCW0805-1.0K-E3	Vishay	CRCW08051K00FKEA	SMD 1k 1% Resistor	SMD 0805	5	$0.03	$0.15
595-SN74CBT3257DR	Texas Instruments	SN74CBT3257DR	Signal Switche 4-Bit 1-of-2 FET	SOIC-16	1	$0.64	$0.64
502-L712RA	Switchcraft	L712RA	2.5MM DC Jack	PCB	1	$3.79	$3.79
538-08-50-0106	Molex	08-50-0106	Molex KK Series 0.156" Crimp Terminal		50	$0.08	$4.00
538-09-50-3021	Molex	09-50-3021	Molex KK Series 0.156" Crimp Terminal Housing 2-Circuit		5	$0.11	$0.55
538-09-50-3031	Molex	09-50-3031	Molex KK Series 0.156" Crimp Terminal Housing 3-Circuit		5	$0.13	$0.65
538-09-50-3041	Molex	09-50-3041	Molex KK Series 0.156" Crimp Terminal Housing 4-Circuit		2	$0.22	$0.44
538-09-50-3051	Molex	09-50-3051	Molex KK Series 0.156" Crimp Terminal Housing 5-Circuit		1	$0.28	$0.28
538-26-48-1241	Molex	26-48-1241	Breakaway Headers - PCB 24-Circuit	Through-Hole	5	$1.47	$7.35
552-PSA-31U-150-R	Philong	PSA31U-150-R	15V 2.0A Switching Wall Mount Power Supply		1	$28.45	$28.45
						Mouser Total	$71.03
Sparkfun SKU#	Description	Cost					
DEV-00666	Arduino USB Board	34.95					

Bill of Materials (Mechanical)						
Supplier	Supplier Part#	mfr. Part #	Description	Qty	Cost p. u.	Total
Jameco	224022	42BYG016-R	Unipolar Stepper Motor 7.5Deg 12V 75Ohm	2	$20.35	$40.70
SDP/SI	S1164Z-048A040	S1164Z-048A040	48-Pitch 40-Tooth Aluminum Alloy Spur Gear	1	$14.24	$14.24
SDP/SI	A 1B 1-T48010	A 1B 1-T48010	48-Pitch 10-Tooth Brass Pinion	2	$6.68	$13.36
SDP/SI	S1164Z-048A030	S1164Z-048A030	48-Pitch 30-Tooth Aluminum Alloy Spur Gear	1	$13.20	$13.20
Home Depot	n/a	n/a	4'x8' Birch Plywood	1	$45.00	$45.00
Home Depot	n/a	n/a	5/16 Fine Thread Nuts	5	$0.20	$1.00
Home Depot	n/a	n/a	5/16" Washers	5	$0.20	$1.00
Home Depot	39003095485	n/a	Lazy Susan	3	$3.67	$11.01
Home Depot	n/a	n/a	Metal Epoxy	2	$2.37	$4.74
Home Depot	n/a	n/a	3'x.5" Aluminum Rod	2	$6.00	$12.00
Home Depot	n/a	n/a	1" Corse Wall Screws	100	0.02	$2.00
Home Depot	n/a	n/a	1.75" Corse Wall Screws	100	$0.02	$2.00
Home Depot	n/a	n/a	8" Concrete QuickTube	1	$5	$5.00
Home Depot	n/a	n/a	#6 Threaded Shaft	1	$1.00	$1.00
Home Depot	n/a	n/a	#6 Nuts	1	$0.99	$0.99
Home Depot	n/a	n/a	1/2" Bolt	3	$0.20	$0.60
Home Depot	n/a	n/a	1/2" Bolt Wood Anchor	3	$0.20	$0.60
eBay	n/a	n/a	Chamerlain Liftmaster Worm Gear 32Teeth & Worm	1	$19.95	$19.95
eBay	n/a	n/a	1 oz. Copper Clad Board 8.5"x11"	1	$1.00	$1.00
eBay	n/a	n/a	6" Primary Mirror	1	$40.00	$40.00
Orion Telescopes	n/a	n/a	1.75" Seconary Mirror	1	$20.00	$20.00
Orion Telescopes	n/a	n/a	3" Rack Pinion Focuser	1	$15.00	$15.00
Ace Hardware	n/a	n/a	1/2" Diamater Brass Washer	2	$2.75	$5.50
Kinko's	n/a	n/a	Transparency Paper x 5	1	$2.50	$2.50
Memorex	n/a	n/a	Clear CD-R	5	$0.25	$1.25
				Mechanical Total		$273.64

Total Cost: $379.62

9. Problem Encountered and Comments

- Our project requires high precision. Our mechanics have encountered "slop" where things were not as accurate as we would have liked. After slowing down each step of movement we were able to achieve a more accurate result.

- When the worm gear turned, it would try to move left and right due to the force pushing back from the gear in part B. We then put ring clips at the two ends against the piece of wood embracing the worm gear shaft. A piece of wood was drilled into the braces to help durability.

- The break sensors for the encoder would always read "high." We added a 47 kOhm resistor which lessened the intensity of the break beam.

- Voltage regulators would get abnormally hot. We installed heat sinks and fans to resolve the issue.