Powered Newtonian Telescope

Senior Project Final Report – Fall 2022

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Version: 3.0

Submitted in partial fulfillment of the requirements of CST471

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REVISION HISTORY

Version:	Revision Date:	Revision Description:	Author:
0.0	10/14/2022	Rough draft	Nathan Wiley
1.0	10/26/2022	Requirements complete	Nathan Wiley
2.0	10/27/2022	Added comparison matrices and part selection	Nathan Wiley
3.0	12/12/2022	Reformatted as report, added memos, diagrams, and table of figures	Nathan Wiley

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1. CONCEPTUAL OVERVIEW

The basic idea of this project is to create a telescope that will adjust what it points at with an embedded device. The movement would be calibrated to coordinate system, and commands could be sent to the device over a network that would allow the telescope to point to, and track, a given coordinate. The main requirements are necessary for the project to be considered complete. The stretch goals are what the project would look like if all main requirements are met, and the time and resources to achieve them are available.

2. REQUIREMENTS SPECIFICATION

1. **Shall pivot a telescope**
    a. Telescope shall pivot at a rate of at least 0.25 degrees per minute.
    b. Shall be accurate enough to point the telescope within 3600 arcseconds (1 degree) of the desired angle.
2. **Shall be able to keep accurate time**
    a. Shall keep onboard time within 2 seconds of time kept at www.time.gov
3. **Shall use a control system**
    a. The control system shall compute the local sidereal time within 2 seconds of real time (co-dependent on req. 2a).
    b. Control system shall reference a database of stellar objects.
    c. Shall receive instructions over Ethernet
    d. Shall execute movement instructions (co-dependent on req. 4b).
4. **Shall have a network interface**
    a. Shall use Ethernet and ethernet protocols
    b. Shall receive movement instructions over Ethernet
5. **Shall use a display**
    a. Display shall signal at least two of the states the system is in (I.E. Moving, or Idle).

2.1 STRETCH GOALS

1. **May have a camera**
    a. Should have a resolution of at least 2MP (1080p)
    b. Should have functionality to save to an SD card
    c. May include networked file transfer of images
    d. May include counter rotation functionality (hardware or software)
2. **May use RTC module**
3. **May include GPS module**
4. **May include Wi-Fi in addition to Ethernet**
5. **May include cooling system for primary mirror**
    a. May be a fan, if so, should move air at least 10 CFM

3. PART SELECTION AND DESCISION MATRICES

In each section below, a comparison matrix for each component will be shown followed by discussion and selection of the component. The discussion will highlight the reasons and thought process behind the choice of the component. Each selected part will be compiled at the end of the report with web links to their respective online stores. Ordered parts will have the estimated arrival date shown.

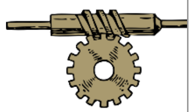
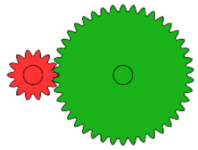
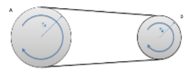
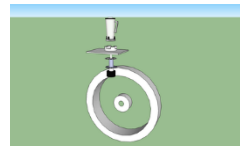
3.1 DEVELOPMENT BOARD

Picture:			
Board Name:	BeagleBone Black - Rev C	Raspberry Pi 3 Model B V1.2	Raspberry Pi 4 Model B
Manufacturer:	Texas Instruments	Raspberry Pi Foundation	Raspberry Pi Foundation
Processor Clock Speed:	AM3358 @ 1GHz	BCM2837 @ 1.2 GHz	BCM2711 @ 1.5 GHz
Memory:	512MB DDR3L DRAM 4GB 8-bit eMMC Flash	1GB RAM	4GB LPDDR4-2400 SDRAM
Network Interface:	Ethernet	WiFi, Ethernet	Dual Band WiFi, Gigabit Ethernet
General Purpose I/O pins:	2x 40 pin headers,	1x 40 pin header	1x 40 pin header
Extra Features:	NEON floating-point accelerator, microHDMI, 1x USB 2.0	HDMI, 4x USB 2.0	HDMI, 2x USB 2.0, 2x USB 3.0
Cost:	$65.99	$0 (Already owned)	$168.88

Discussion: The BeagleBone's main attractive features were the high pin count and the floating-point accelerator, it could prove useful when driving stepper motors at high pulse rates. However, since this project should only include a maximum of two motors and a few peripherals, the pins would be excessive. The Raspberry Pi 4's upgrades over the 3 are nice, but they don't justify themselves with the current price. The Raspberry Pi 3 seems to be the sweet spot with an included RTC module, WiFi, Ethernet, SD card slot, and potential camera connector.

Selection: Raspberry Pi 3 Model B V1.2

3.2 GEARING

Picture:					
Drive Criteria:	Worm Gear	Spur Gear	Belt Drive	Friction Drive	Direct Drive
Positioning:	good	good	good	very good	good
Tracking:	good	fair	good	excellent	good
Stiffness:	poor	poor	very low	very high	fair/good
Smoothness:	good	fair	fair/very good	excellent	good
Gear Ratio:	very high	low	low/moderate	high	n/a
Efficiency:	very low	high	high	very high	very low
Zero Backlash:	no	no	yes	yes	n/a
Periodic Error:	small/mod	large	small	very small	very low
First Period:	2-4 min	1/tooth	2-4 hours	1 hour	n/a
Cost:	high	moderate	low	moderate	very high

Discussion: The table above is from DFM Engineering Inc., it shows the pros and con of the different ways to drive a telescope. Initially, the worm gear was going to be the implemented drive type because it offers very high torque with precise control, but the prices were too high. Another reason against the worm drive, as well as the spur gear and friction drive, is that it requires very precise centering, and because this is an embedded project and not a manufacturing or mechanical project, there is no guarantee of precision. The belt drive can be easily adjusted with tensioners, which allow for some error in the centering of the pulleys. The belt drive also has zero backlash, which will help the telescope to remain stable and not rattle or vibrate when operating. Because of these reasons, and the fact that it is cheaper than the other options, the belt drive is going to be what connects directly to the vertical and horizontal movement axis.

Selection: Belt Drive

3.3 MOTORIZATION TYPE

Picture:			
Drive Name:	Stepper Motor	DC Motor	Servo Motor
Speed Control Method:	Individual steps, micro-stepping	Voltage	PWM
Torque at low RPM:	High	Low	High
# of wires	4 – 8	2	3
Continuous rotation:	Yes	Yes	No
General Cost:	Intermediate	Low	High

Discussion: Above is a table of generalization about the different motor types. Since the telescope require to be precisely controlled with high torque, the stepper motor is the clear winner once cost is factored in. Now that the type of motor is selected, an individual stepper motor still needs to be selected. Below is a table of different stepper motors and their pros and cons.

Selection: Stepper Motor

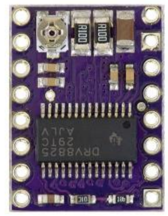
3.4 STEPPER MOTORS

Picture:			
Model Number:	17HS19-1684D-PG100-E1000	23HS22-2804S-HG50	17HS15-1584S-PLMG100
Stepper Class:	NEMA 17	NEMA 23	NEMA 17
Gear Type and Ratio:	Economy Planetary, 100:1	High Precision Planetary, 50:1	High Precision Planetary, 100:1
Backlash:	<= 1 deg (3600 arcseconds)	<=1.6 deg (5760 arcseconds)	<=0.83 deg (3000 arcseconds)
Max Torque (With Gearbox):	4Nm (566.56oz.in)	20Nm (2832.8oz.in)	5Nm(708oz.in)
Encoder:	Yes	No	No
Current:	1.68A	2.8A	1.58A
Cost:	$63.08	$90.81	$37.16

Discussion: For stepper motor selection, a high gear ratio is a must because it must have enough torque to move the scope and enough steps per rotation that it provides smooth movement after being geared down. The second option doesn't have as much precision as the other two. The first option includes an encoder on the back of the stepper motor itself which seems attractive; however, the higher backlash and price is higher than the third option while providing less torque. If the need for an encoder arises, then it can be added on after. The third option's gearbox also has a waterproof rating of IP54 which protects the gears from dust and moisture.

Selection: 17HS15-1584S-PLMG100, NEMA 17

3.5 STEPPER MOTOR DRIVER

Picture:			
Driver Name:	DM542T	DRV8825	A4988
Max Rated Amperage:	4.20A	2.2A	2A
Micro stepping:	Up to 1/256	Up to 1/32	Up to 1/16
Price:	$20.99	$18.95	$14.45

Discussion: The selected motor requires 1.58A to run, and the A4988 could only provide that if it was cooled with heatsinks and fans. The DRV8825 could handle that load better, but not with much room to spare, so it would likely get hot too. The DM542T can easily handle the load with high micro stepping resolution as well.

Selection: DM542T

3.6 SELECTED PARTS

Part:	Link:	Order Date:	Price:
Raspberry Pi	https://thepihut.com/products/raspberry-pi-3-model-b?src=raspberrypi	N/A (Already Owned)	0
Nema 17 Stepper Motor	https://www.omc-stepperonline.com/nema-17-stepper-motor-l-40mm-gear-ratio-100-1-plm-series-planetary-gearbox-17hs15-1584s-plmg100	10/28/2022	$37.16
DM542T Digital Stepper Driver	https://www.omc-stepperonline.com/digital-stepper-driver-1-0-4-2a-20-50vdc-for-nema-17-23-24-stepper-motor-dm542t	10/28/2022	$20.99
Power Supply	https://www.amazon.com/dp/B08GFQZFC1?ref=ppx_yo2ov_dt_b_product_details&th=1	11/28/2022	39.99

4. BLOCK DIAGRAM

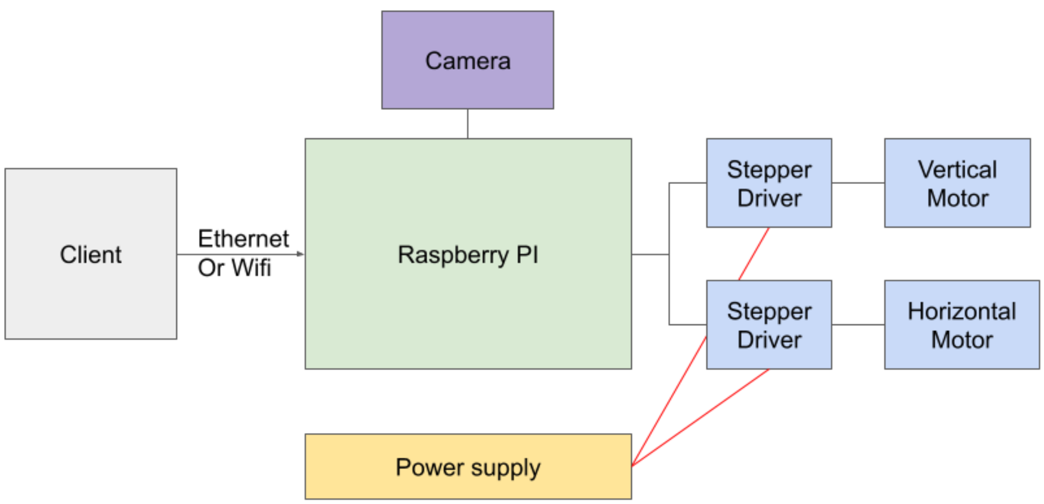


Figure 1: Block Diagram

Above is a block diagram of the project. This is a very general overview to show how each part will connect with one another. A more detailed diagram showing pin connections and voltage levels will be completed at the beginning of winter term.

5. SOFTWARE DEVELOPMENT ENVIRONMENT

Since the project is running in a Linux environment, for some it might seem natural to adopt IDEs like Geany or Thonny, and editors such as VIM or Emacs, while using python as the primary language. These options would take valuable time to learn and get accustomed to. Instead, since it is familiar, Visual Studio, C++, and GitHub will be used. The Home PC will be configured to remotely build, debug, and execute code through Visual Studio to the Raspberry Pi over SSH. The source control is set up through GitHub which is accessed through Visual Studio as well. This will result in much faster software development as it allows for the write, build, debug, test cycle to be accomplished all in one place, without the need for the Home PC to be directly connected to the Raspberry Pi. This will not only speed up the development time, but also allow the device's code to be updated on the fly once it is complete.

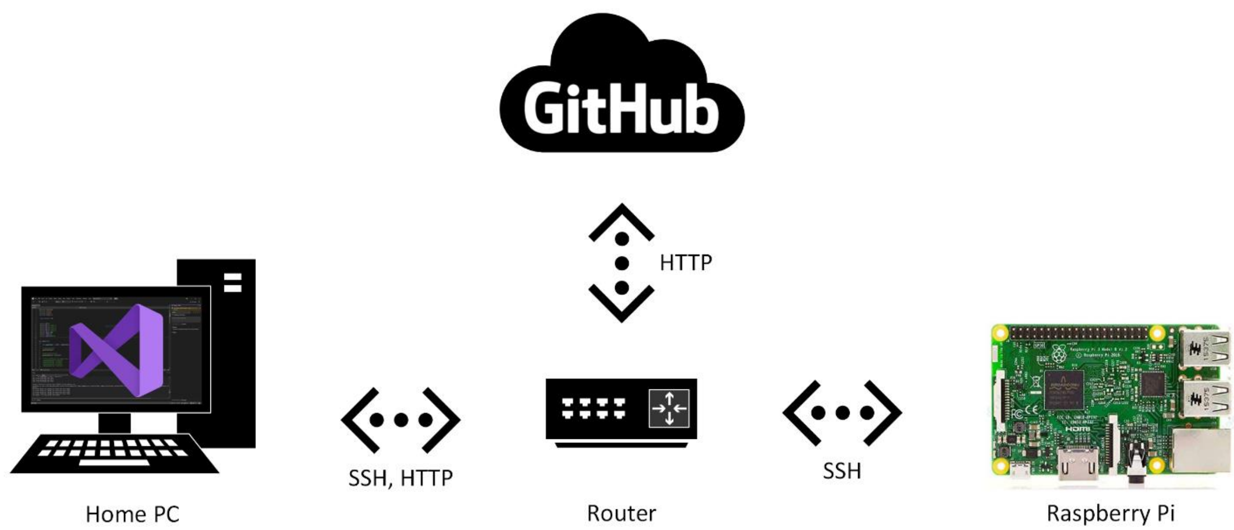


Figure 2: Software Development Environment

As of the end of Fall 2022, All that has been completed on software was a basic LED blink and a simple stepper motor rotation routine, but this was done using the setup as seen and described above, so it was possible to step through and debug code that was written on the Home PC and ran remotely on the Raspberry Pi by simply hitting F5 and pushing to GitHub in the same window.

6. PHYSICAL CONSTRUCTION

Most of the documentation on the physical construction of the telescope is in the memos, so this section will be a brief overview of the progress so far. The telescope parts that were already acquired were the primary and secondary mirrors, tube, eyepiece, and star finder. The parts that needed to be built were the base, vertical and horizontal axis, and tube rings to hold the tube or body of the telescope. Autodesk Inventor was used to design plywood and 3D printed parts to accomplish this.

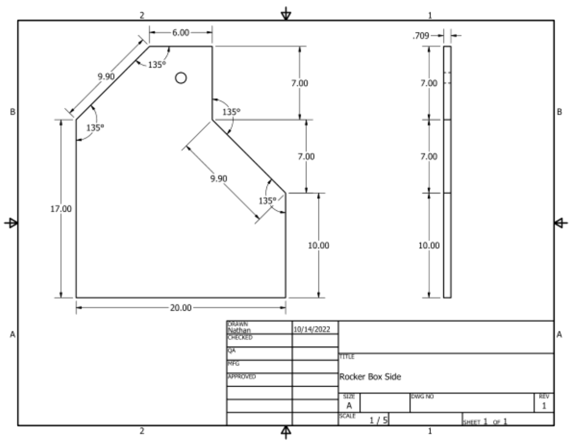


Figure 8: Side Panel

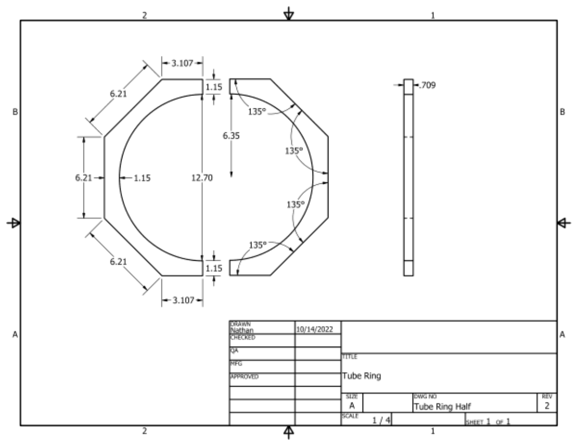


Figure 7: Tube Ring

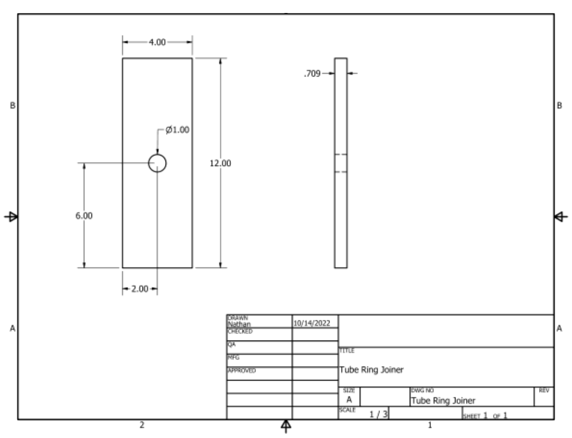


Figure 6: Tube Ring Joiner

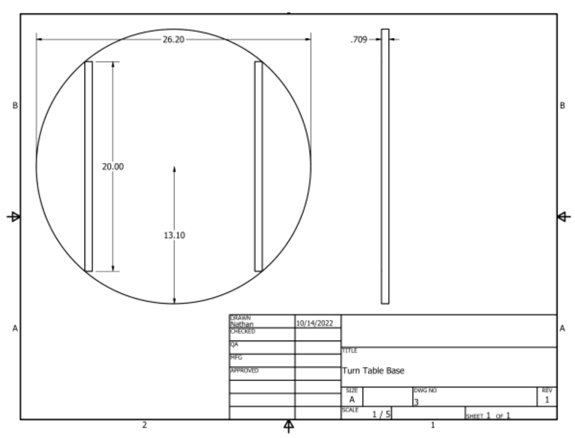


Figure 5: Turntable

Figure 4: 3D Printed Bearing

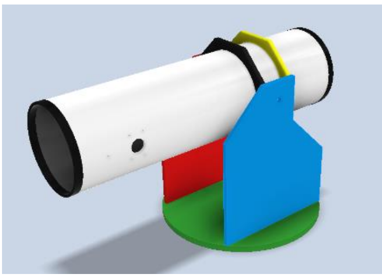


Figure 3: Autodesk Inventor Assembly

7. TIMELINE

Construction is almost complete on the telescope. The remaining steps are to purchase a belt and pully to attach to the vertical bearing and the horizontal turntable, and design or purchase a waterproof housing to store all of the electronics. So far, all parts have come in and things are mostly on schedule.

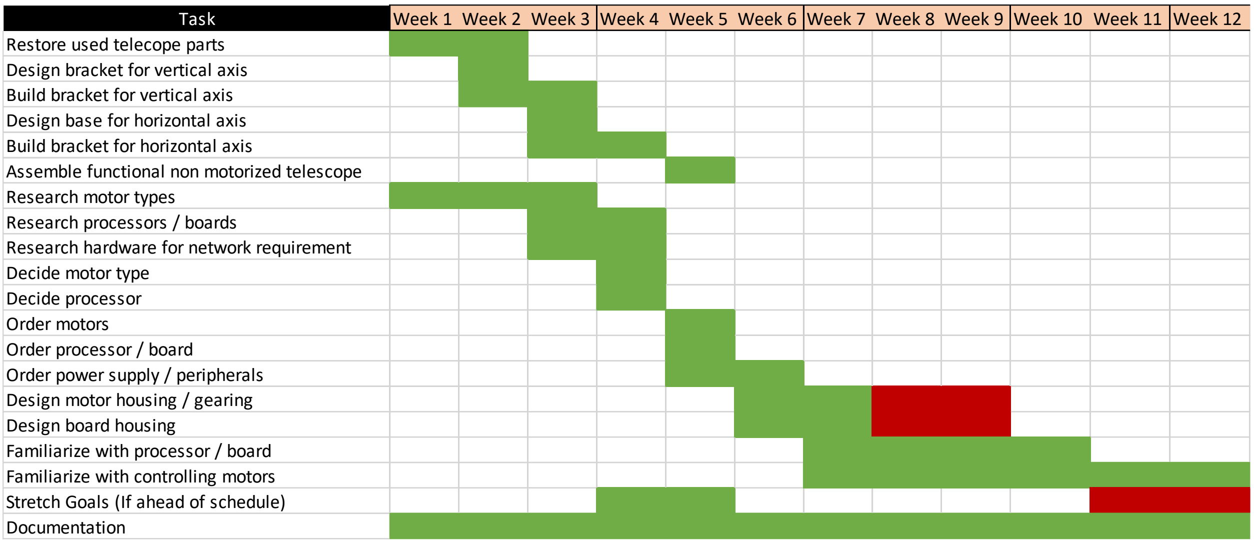


Figure 9: Timeline

8. COST

Primary Mirror	$ -
Secondary Mirror	$ -
Tube Assembly	$ 67.95
Dobsonian Base	$ 134.30
Board	$ -
Motors	$ 74.32
Drivers	$ 41.98
Power Supply	$ 39.99
Paint & Sandpaper	$ 48.96
Hardware (Bearings, legs, levels)	$ 61.76
Shipping	$ 26.41
Total	$ 495.67

Figure 10: Part Cost

The part cost of this project is $495.67

The engineering cost for this term is as follows:

15 hrs./week * 10 weeks = 150 hrs. @ $50/hr. = $7,500

This added to the part cost = $7,996 for this term.

REFERENCES

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Texereau, J. (1957). How to Make a Telescope.