WENTWORTH INSTITUTE OF TECHNOLOGY DEPARTMENT OF ENGINEERING

BSEN Junior Design Summer 2019

Spatial Symphony Final Report

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Submitted to Professor James McCusker, PhD

By:

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ABSTRACT

A kinematic art installation is being developed to enhance the visual appeal and general ambience of the Douglass Schumann Library. The final installation will include a 20'x40' two phase gantry system and approximately 40 flower shaped devices which will open and close. Several sub-systems have been developed by previous student design groups. A redesign of the primary gantry, improvement of the cable management system, and development of a general maintenance and repair system were the focus of this Summers design period.

Fig. 1- *A rendering of the proposed Spatial Symphony installation [1]*

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BACKGROUND

The Spatial Symphony kinematic art installation is a developing collaborative project is being developed to enhance the visual appeal and ambiance of the Douglas Schumann Library. The current state of the installation has directly resulted from a collaborative effort which has spanned several semesters of Electromechanical and Interdisciplinary Junior and Senior design projects with additional assistance from non-student professionals and other Wentworth academic departments. The project was first conceived in 2016 by Architecture students when Casey Anderson generously donated $50,000 to fund the project with the intent of promoting interdisciplinary collaboration within the Wentworth community [1].

In the Spring 2019 semester, a group of 5th year Electromechanical students developed opening and closing mechanisms to be used on flower shaped structures to be implemented in the final Spatial Symphony installation. The team also developed a Unistrut mounting system for the full-size system footprint. Prior to the development of the newest flower motion mechanisms, a group of 4th year Electromechanical students made improvements to secondary gantry motion boxes which provide motion to the flower mechanisms in the up and down (Z) and sides to side (Y) axes.

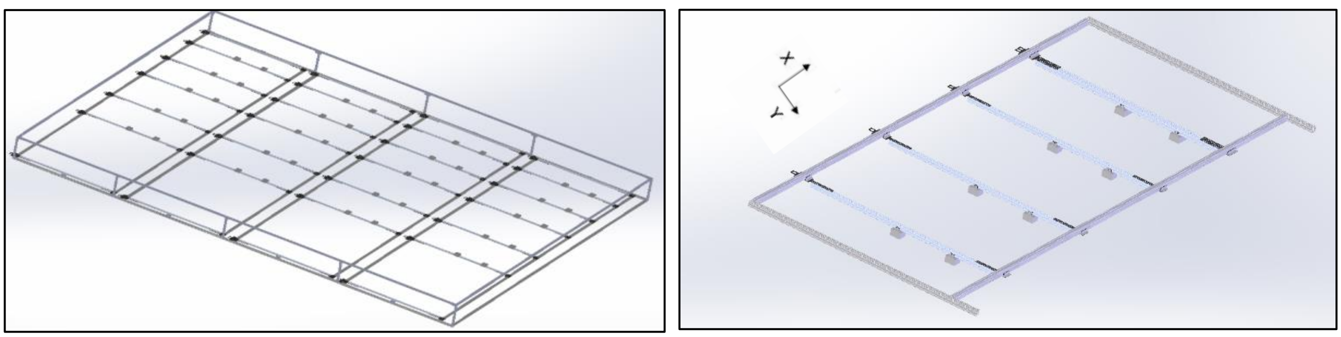


Fig. 2a (left) and 2b (right)*- Current completed system foot print with 20 mounted primary gantry arms and 40 secconary gantry motor assemblys all mounted on a Unistrut suspension system (left) [1]; single 8'x20' primary gantry frame section, 4 primary gantry arms and 8 secondary motor housing devices (right) [1].*

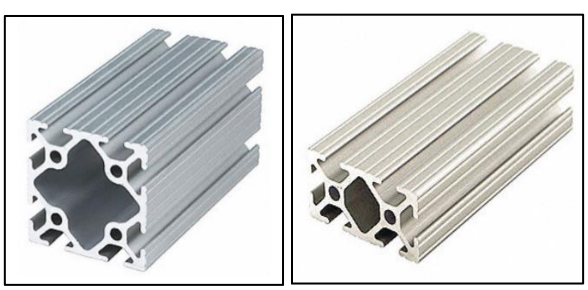


Fig. 3a (left) & 3b (right)*- 25-5050 (left) and 25-2550 80/20 extrusion profiles used to construct system frames [1].*

Fig. 4a (left) & 4b (right)*- First (left) and final (right) iterations of the flower mechanism designed by the Spring 2019 BELM 5th year design group [1].*

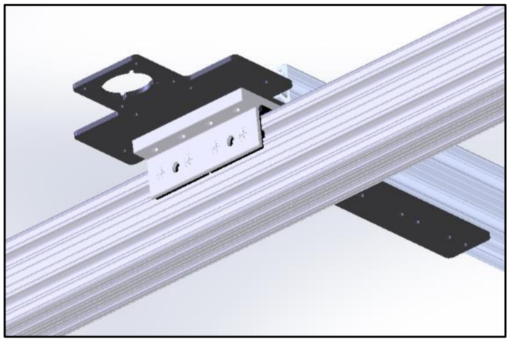


Fig.5*- SolidWorks assembly model of mounted primary gantry motion system [1]. The system uses a nylon bearing and NEMA 23 motor mount to horizontally attach to 20' length of 25-5050 80/20 aluminum extrusion [2].*

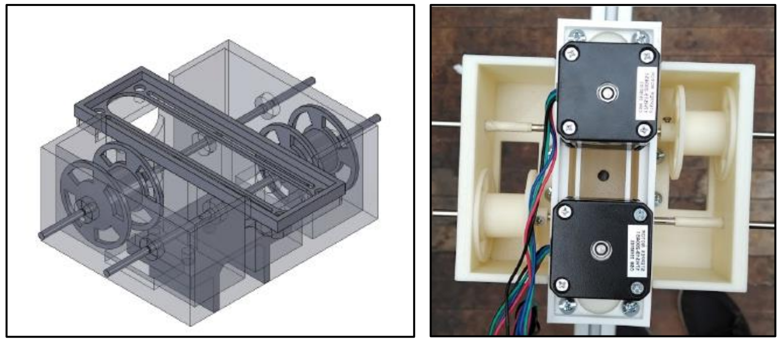


Fig. 6a (left) & 6b (right)*- SolidWorks assembly model and picture of final secondary gantry housing developed by the 2019 BELM group; assembly mounts to frame sections shown in Figs 2a & b and raises/lowers flower mechanisms in Figs. 4a & b [2].*

Proceeding the redesign of the secondary gantry flower motion modules, a group of Junior Interdisciplinary Engineering students designed a cable management system for the first iteration of the secondary gantry motor housing/flower pullers. The system mounts the primary gantry arms. The primary gantry arms are driven by a belt and pinion system that is shown in Fig 5. The system mounts on a piece of 25-2550 series 80/20 and connects to the secondary gantry motor housing/flower puller system.

Fig.7*- A shortened primary gantry arm used to test 2018 BSEN Jr. Design cable management system [3].*

Fig.8*- The secondary gantry cable management system mounted on the shortened 25-2550 series primary gantry arm [3].*

The primary objects for the Summer 2019 Interdisciplinary Junior design team will focus on improving the current primary gantry motion system and power distribution/cable management systems. Further details are found in the "Problem Definition" and "Project Objective" sections of this report.

PROBLEM DEFINITION

This Summer, the Interdisciplinary Junior Design team focused on improving both the primary gantry motion and power distribution/cable management subsystems. Primary problem definition consisted of discussion with Professor McCusker who instructed all previous design groups. Since the Spatial Symphony project had seen multiple subsystem redesigns, Professor McCusker was able to inform us which systems still needed improvements and finalization needed for overall system functionality.

The first design task was to improve the linear actuation of the primary gantry to improve overall rigidity of the previous belt and pinion driven system. The second design task was to improve system power distribution/cable management of the overall system through design of a cable management system for the entire system. The second design task scope included connection of all subsystems to the primary power distribution board and main power breaker. Both subsystem designs were selected with the overall goal of improving system functionality, utility, and aesthetic.

PROJECT OBJECTIVES

Upon defining semester design goal, the team created a set of design goals to be completed within the three-month design period. The objects were divided into two categories:

1. Primary Gantry Redesign:

For the primary gantry, Team Two will develop, design, and test an upgrade of the current primary gantry belt and pinion motion system. The design will utilize a rack and pinion configuration to improve stability and rigidity of the primary gantry system Doing so, in turn, will improve the stability of the secondary gantry motion. Due to weight of the secondary gantry components, which include flower modules and linear motion components, the rack and pinion system must to be able to withstand both dynamic and static forces caused by the secondary gantry system motion. Once completed primary gantry arm will be mounted and tested on a 8’x20’ frame section. The final rack and pinion system shall be designed for ease of scalability, so the final design can be used on the projects full footprint.

2. Power Distribution and Cable Management

The previous work done on the electrical side of the Spatial Symphony includes a custom-made PCB that handles the power distribution and communication between the stepper motors and an Arduino microcontroller. Again, there must be a balance, but this time for mechanical and electrical design so the entire system can function successfully. The wire management system must be able to work concurrently with the redesigned primary gantry system and be compatible with the current secondary gantry cable management system. Once completed, the power distribution and cable management will be mounted and tested on a 8’x20’ frame section. Both electrical subsystems should be designed to successfully scale up and be implemented on the projects full footprint.

RESEARCH

After defining project objectives, the Interdisciplinary Junior Design team needed to research mechanical and electrical systems with similar functionality to get a better sense of what was needed to achieve the established design objectives. For the primary gantry motion system, previous student documentation was used to get an understanding of how the current design worked. Further research was done through OpenBuilds.com, an open source community and part store which provides build solutions and ideas to for the CNC, 3D Printing, and other hobbyist on the online community. Extensive research into rack and pinion motion and mounting was also necessary. Use of past student design documentation was also important in understanding power distribution system and cable management systems. Research regarding cable termination and user controls for the system were also important before proceeding with design implementation. After completing all relevant research, the team proceeded to design both subsystems. All relevant research, team meetings, and project consultations were documented by use of weekly memos and personal design notebooks.

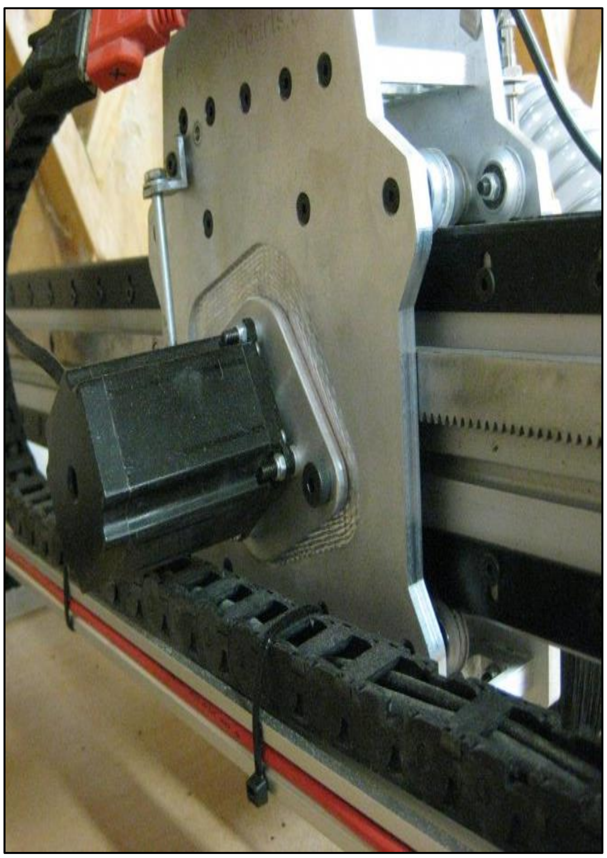


Fig.9- A photo of the "Area 51" CNC router build from OpenBuilds.com [4].

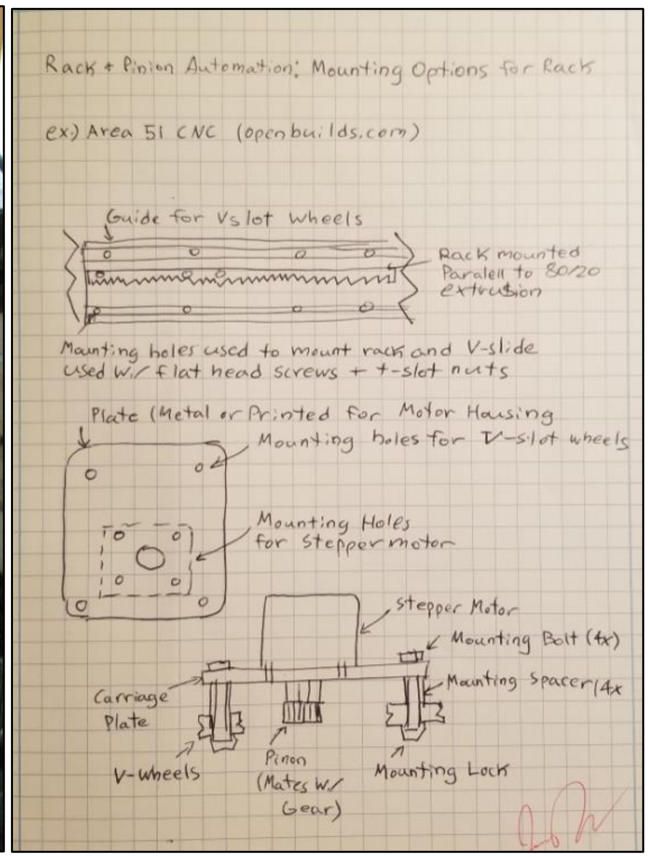


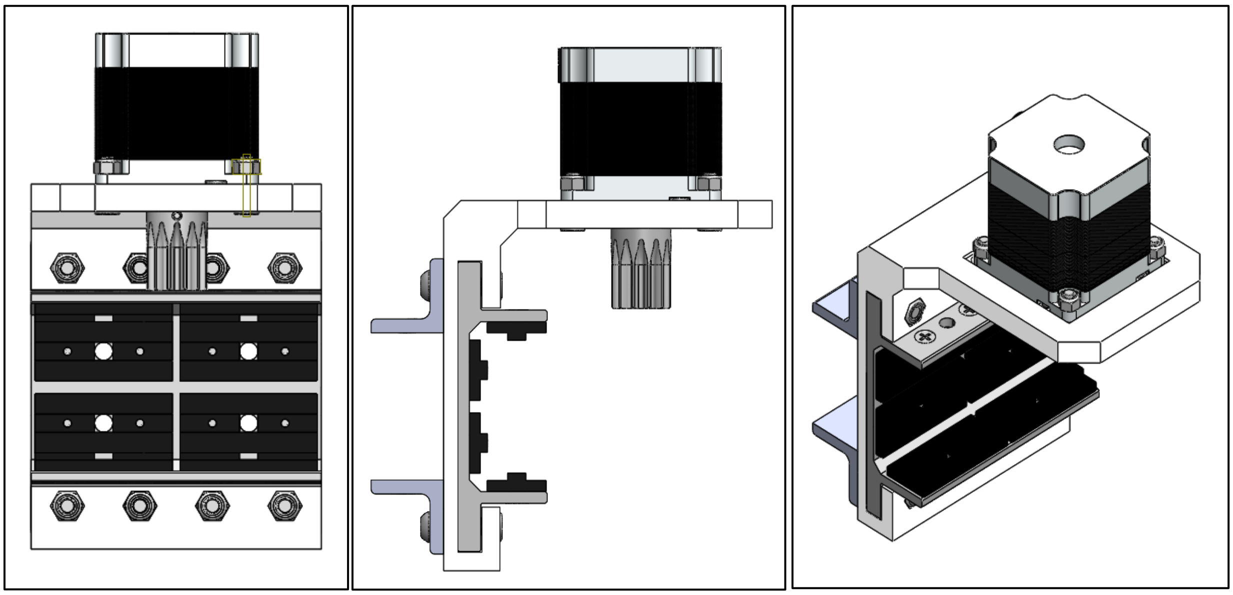
Fig.10- *A design notebook entry for a rack and pinion system used by the Area 51 CNC build.*

DESIGN

Part 1: Primary Gantry Motion

The final primary gantry design consists of a pinion motor housing, a roller wheel idler system, an 8' 80/20 aluminum extrusion, custom maid brackets, and various mounting hardware. The following SolidWorks models and drawings were used to build a single primary gantry arm:

<u>Pinion Motor Housing</u>



***Figs.11a, b, & c**- Several model views of the pinion motor housing design.*

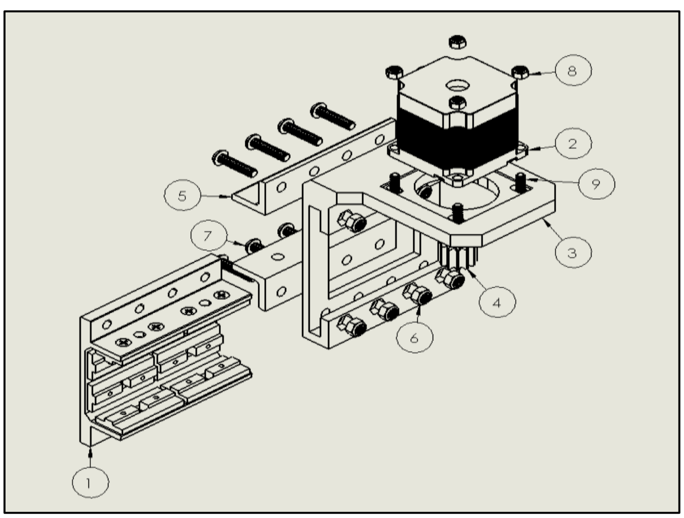
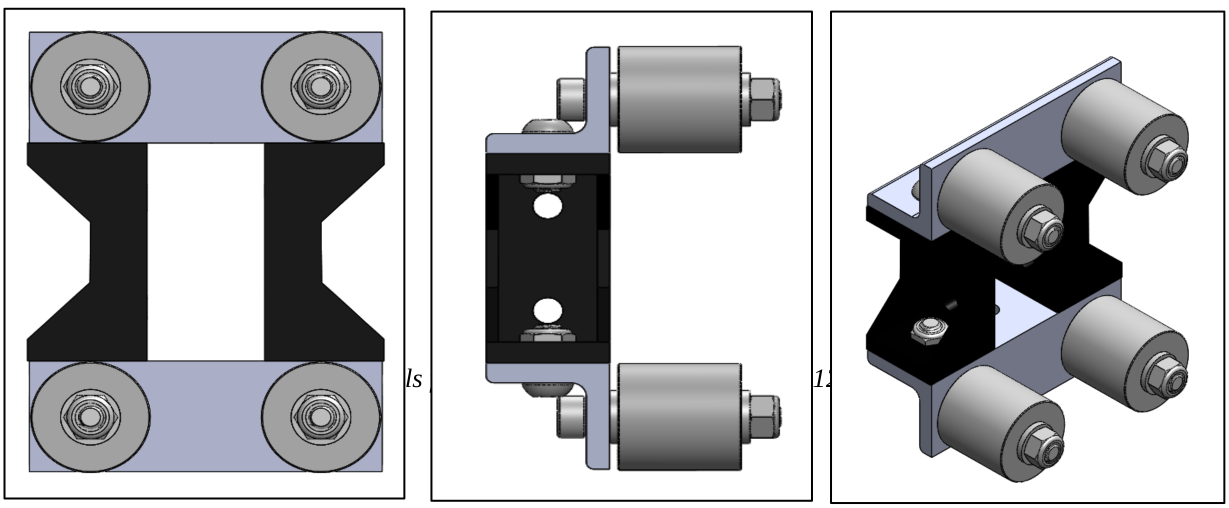


***Fig.12a –** An exploded SolidWorks assembly drawing of a single pinion motor housing.*

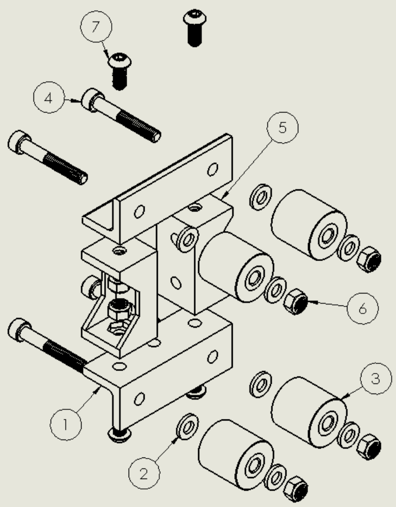
ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	25_6424 Nylon Bearing	Grainger Part #2664N160	1
2	Nema 23 Stepper Motor		1
3	Motor Mount	3D Printed	1
4	Pinion	McMaster Part #2664N160	1
5	Motor Housing Bracket	Custom Steel Bracket, See DWG #2	2
6	M6 Locknut	McMaster Carr #90576A115	8
7	M6x25 1mm Thread Screw	McMaster Carr Part #91239A327	8
8	M5 0.8mm Thread Locknut	McMaster Carr Part #90576A104	4
9	M5X15 1mm Thread Screw	McMaster Carr Part #91290A231	4

Fig.12b – *A bill of materials used for a single pinion motor housing assembly.*

<u>Idler Assembly</u>



Figs.13a, b, & c- *Several model views of the roller wheel idler design.*



ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	Roller Bracket	Custom Steel Bracket; See DWG#3	2
2	M6 Washer	Generic; use equivalent if needed	8
3	Roller Wheel	McMaster Carr #1568T68	4
4	M6X40 1mm Thread Screw	McMaster Carr #91292A142	4
5	Roller Bracket Spacer	3D Printed	2
6	M6 1mm Thread Locknut	McMaster Carr #90576A115	8
7	M6X14 1mm Thread Screw	McMaster Carr #92095A227	4

Fig.14- *An exploded SolidWorks assembly drawing of a single roller wheel idler.*

<u>Custom Components</u>

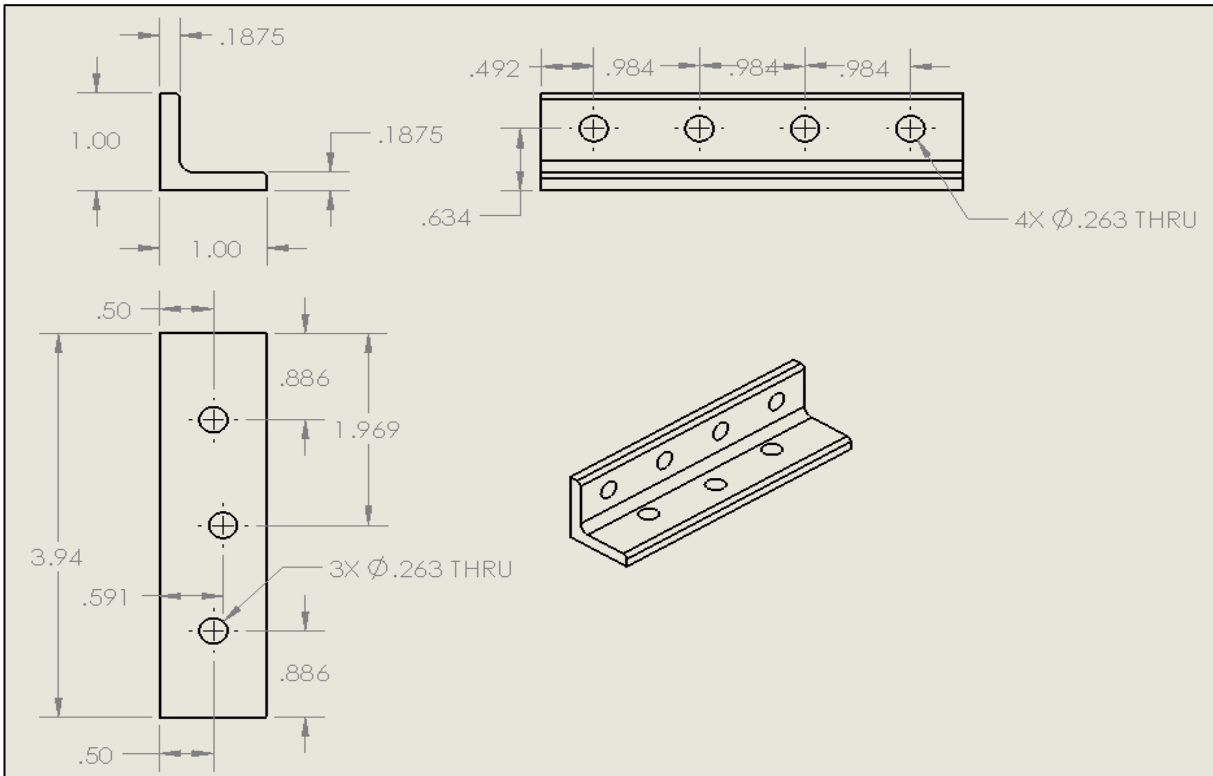


Fig.15- *SolidWorks drawing used to make a single motor housing bracket; two are used in a single pinion motor housing assembly.*

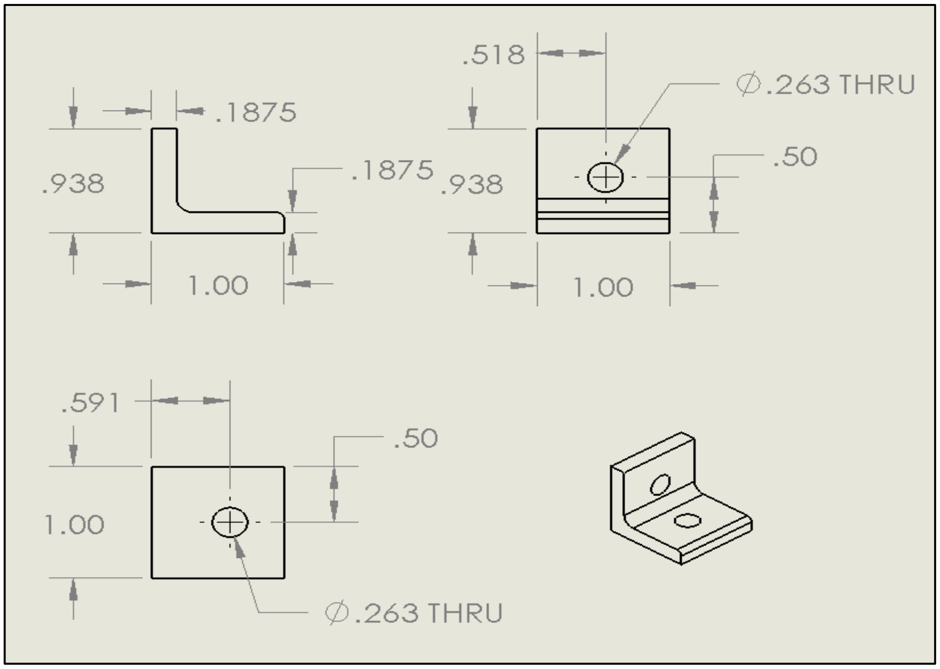


Fig.16- *SolidWorks drawing used to make a single corner bracket; four are used in a single pinion motor housing assembly.*

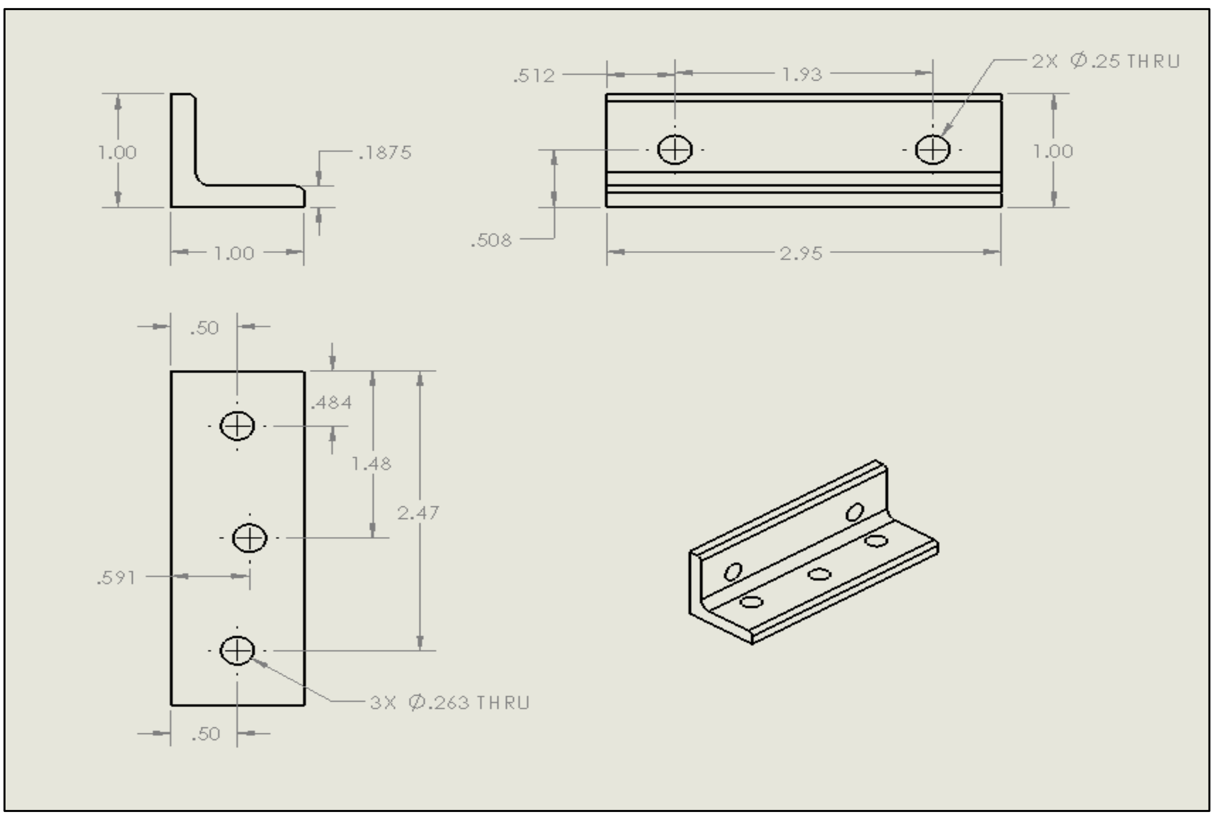


Fig.17- *SolidWorks drawing used to make a single motor housing bracket; two are used in a idler roller assembly.*

Rack Mounting Holes

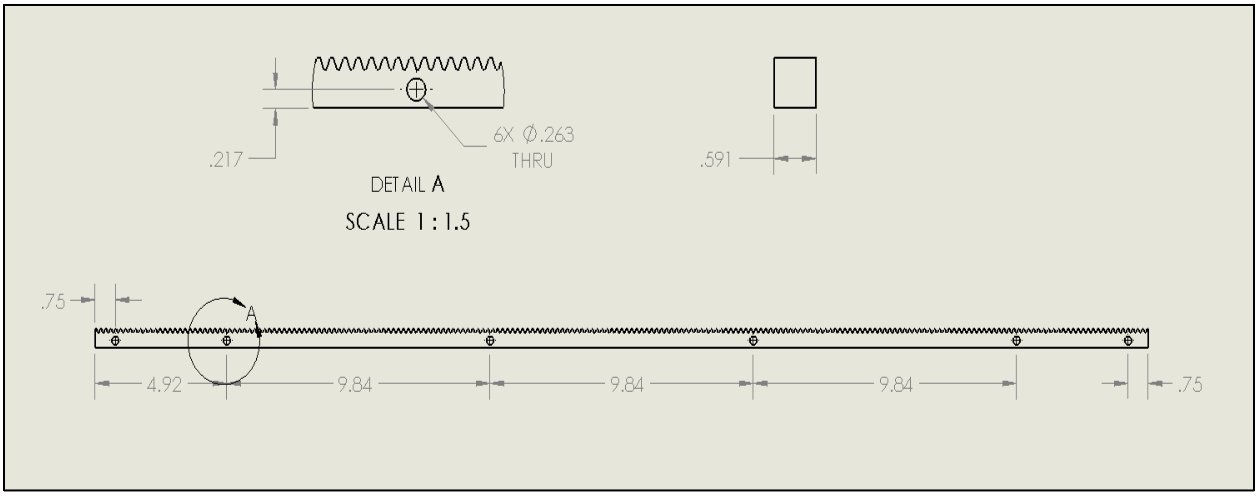


Fig.18- *SolidWorks drawing used to drill mounting holes in a 1000 m length of rack.*

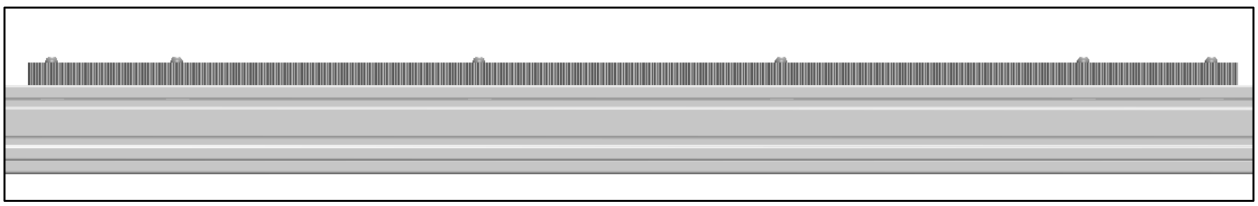


Fig.19- *Model of single 1000 m length of rack mounted on 20' piece of 25-5050 series aluminum; two lengths are used for a sinale run of rack.*

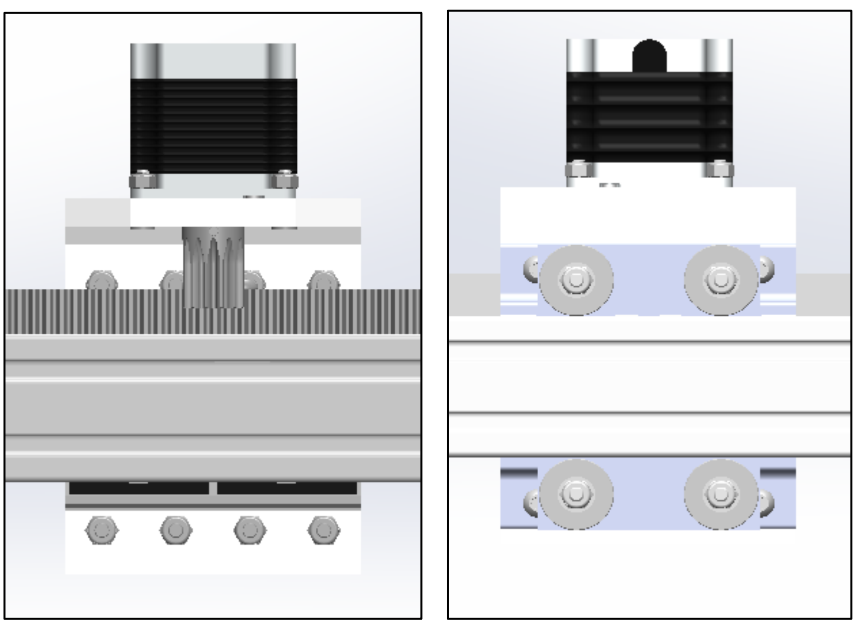


Fig.20a (left) & 20b(right)- *Model of pinion motor assembly mounted on one 2000 m run of rack (left); a model of an idler assembly rolling on the 20' piece of 80/20 (right).*

Completed Design

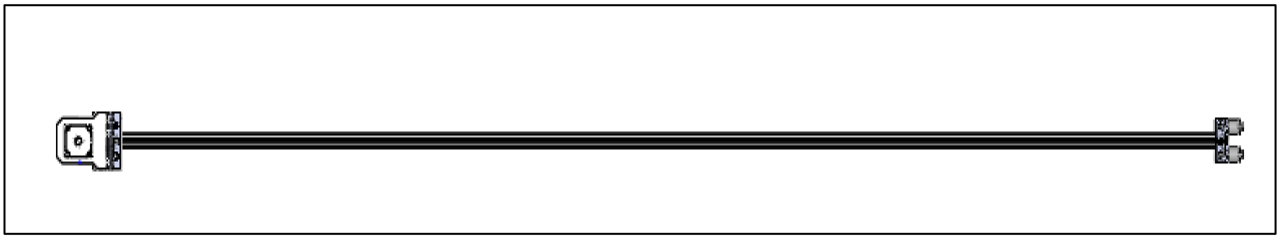


Fig.21- *Model of a primary gantry arm complete with motor mounting housing and idler assembly.*

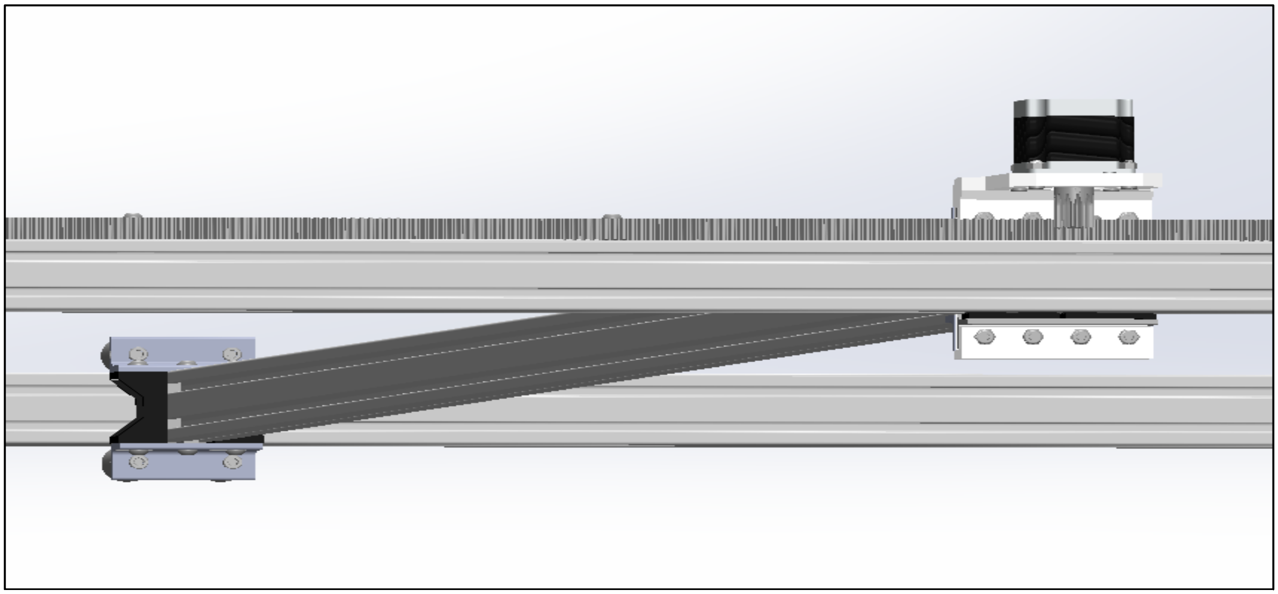


Fig.22- *Model of a primary gantry motion arm mounted to 80/20 frame extrusions.*

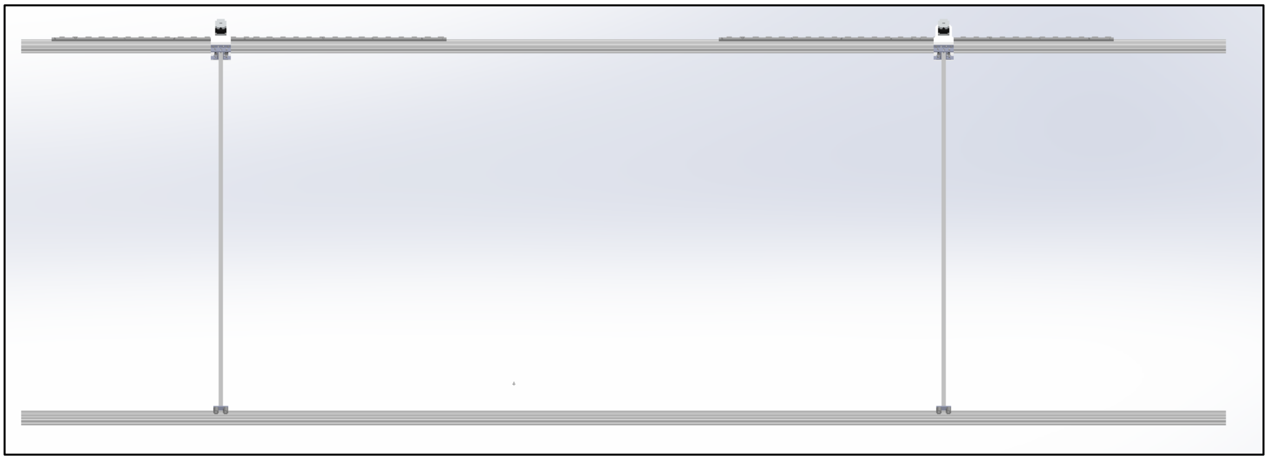


Fig.23- *Two primary gantry arms mounted to an 8'x20 frame.*

**See Appendix A for important design notes.

Part 2: Power Distribution, Controls, and Cable Management

The final design of the cable management system consists of large flexible cable holders mounted to the side of the 20’ 80/20 extrusion. The holders connect to the motors driving the primary gantry motors and can easily be expanded to be used with the secondary gantry components. The holders also come in various lengths and will be easily scaled up to fit the full frame size. To control the currently flowing to the whole system, a switch will be added to the 50V power supply unit that distributes power to every motor. The switch will reduce wear on the main power plug and provide a quick and safe way to cut off the systems power.

To further increase longevity and safety, heat sinks will be added to the driver modules to ensure they don’t burn out during testing. Although only one motor driver will be used during the design phase, many will be used in the final installation. Having several heatsinks will protect against future shorts.

RESULTS

Part 1: Primary Gantry Motion

At the conclusion of the summer 2019 build semester, the team produced one primary gantry arm and has attached it to the 8’x20’ aluminum frame. Due to time constraints, the team was unable to run an autonomous test; however, one primary gantry arm was successfully assembled and manually tested for fit.

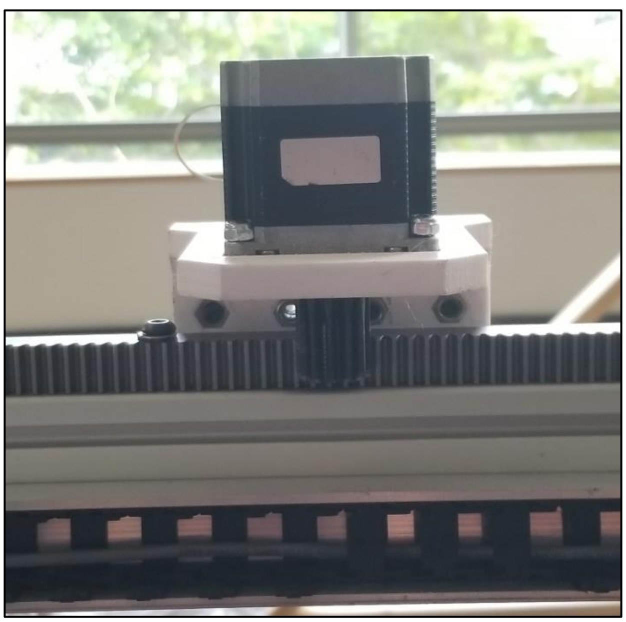


Fig.24- *Mounted motor housing on rack and cable holder; both are mounted to a 20’ 80/20 extrusion.*

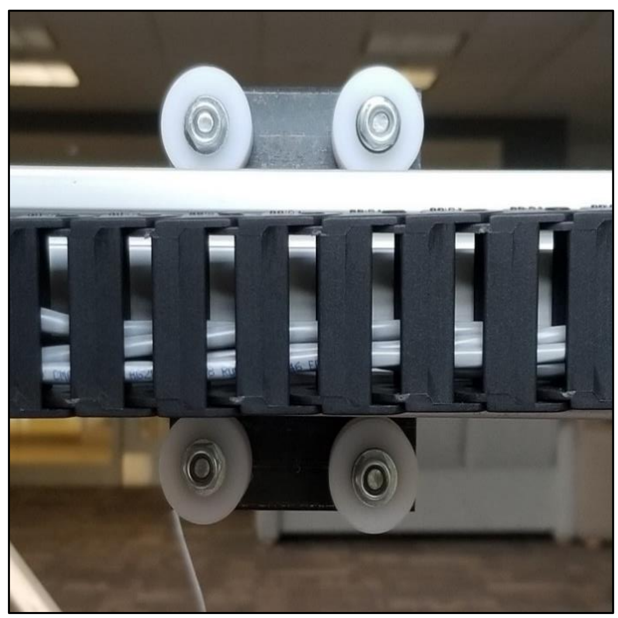


Fig.25- *Mounted Roller assembly and cable holder; both are mounted to a 20’ 80/20 extrusion.*

Fig.26- *Single assembled and unmounted primary gantry arm.*

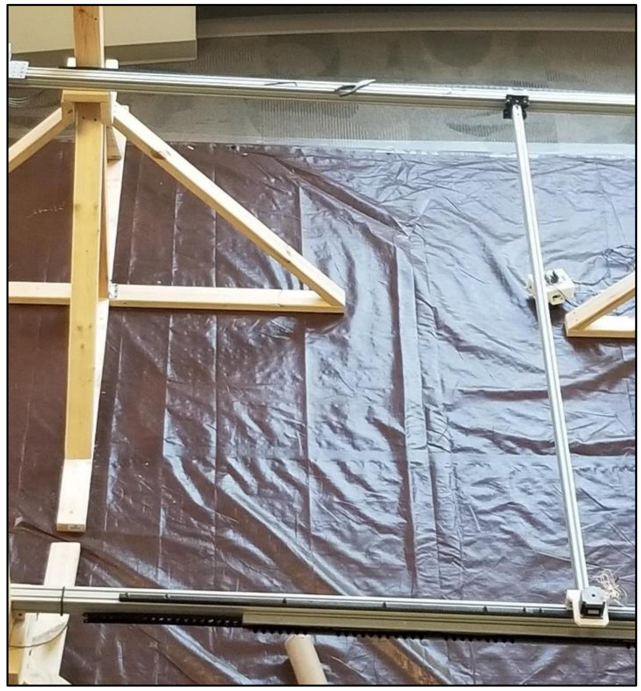


Fig.27- *Single primary gantry arm mounted to 80/20 test frame.*

Part 2: Power Distribution, Controls, and Cable Management

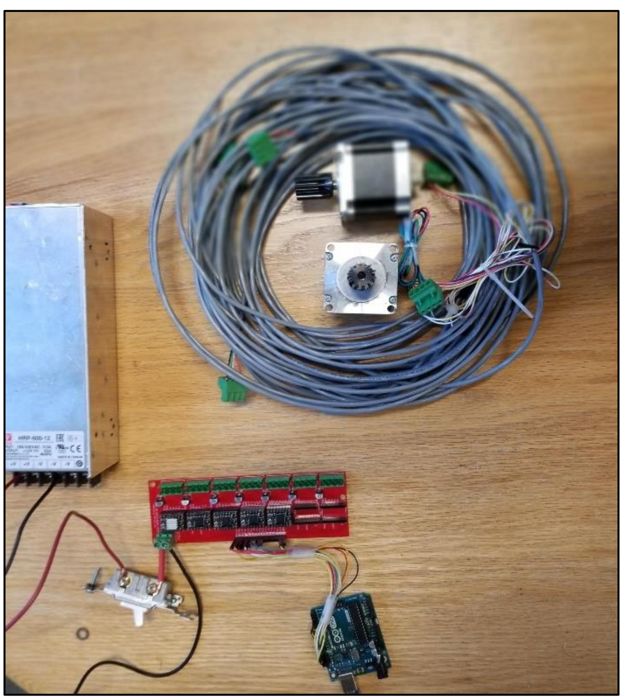


Fig.28- *Modified distribution system and extended cables made for primary gantry motors.*

Fig.29- *Cable management system mounted to 80/20 test rack; used to connect to primary gantry arms.*

DISCUSSION & DESIGN FUTURE

Having designed and implement our semester objectives, the team faced some challenges throughout the design semester. Now having experience working on a highly involved, large scope project, the team would like to provide the following design directives for future groups who may continue work on the Spatial Symphony project. The following are needed to continue testing the current state of our subsystems and scale up our designs:

- Order and install all primary gantry motors; acquire necessary components to replicated the primary gantry arm.
- Mount a second gantry arm to the 20' aluminum frame and autonomously test independent motion of each gantry arm.
- Acquire all necessary components to build four secondary gantry housings and flower modules and related cable management system.
- Mount all secondary gantry and cable management system to primary gantry arms.
- Run an autonomous test to verify two degrees of motion.
- Splice the 50-amp disconnects between the power supply outlet and the AC/DC power supply.
- Order drivers that are rated for higher current loads and redesign the power/signal distribution board to fit them.
- Once two degrees of motion have been successfully tested on the 8'x20' frame, order components to expand design.
- Reference all past team documentation when implementing the design on a larger scale.
- Coordinate with Professor McCusker and other relevant involved parties before proceeding with further design changes.

CONCLUSION

The primary goal of the Spatial Symphony project is to expose students to collaborative, interdisciplinary environment and to enhance the visual appeal of the Schumann Library, an important community space where many Wentworth Students spend significant amounts of time in. The Summer 2019 Junior Design group was fully exposed to a real-life application of collaborative design through the projects large scope. The team was able to successfully make improvements to the primary gantry motion system and power distribution/cable management systems; both of which will contribute to future collaboration and eventual completion of art installation. While building off past student design work and working hand-in-hand with non-student community members, the team learned how important it is to manage team time. Along with this report, the team has submitted other important build documentation.

REFERENCES

[1] Andrade, K.M., Richmond, C.A., DePina, A.J.M., 2019, BELM Senior Design II Final Report

[2] Bednar, J.E.., Schwartz, M.L., Woo, J., 2019, Spatial Symphony: Motor Housing Subsystem

[3] Brown, H., Doherty, R., Stogryn, J., 2018, BSEN Junior Design Final Report

[4] Hytech2k, 2017, "Area 51 CNC Parts F-117 CNC Gear Rack Drive System", from https://openbuilds.com/builds/area-51-cnc-parts-f-117-cnc-gear-rack-drive-system.1428/#openbuilds_files?

APPENDICES

Appendix A: Additional Design Notes & Information

1. All dimensions shown in part drawings are in inches; these represent the closest approximation to the equivalent metric values.
2. Due to large lead times, all 3D printed parts were printed in the Technology Sandbox. Before scaling up the design, it would be wise to test print one of the parts on a higher quality printer in the Additive Manufacturing lab; some dimensions may have to be modified due to tolerancing of higher quality prints. The same applies to the spacer brackets used in the roller assembly.
3. Two 1000 meter long Non-hardened 20° pressure angle racks are used for one section of rack (McMaster Carr part #2485N204). Racks mesh with 20° pinons (McMaster Carr #2664N16). Rack is mounted directly to face of the 20' 80/20 extrusion used in the test rack.
4. All steel brackets were manufacturing using a 6' low-carbon steel stock (McMaster Carr Part #9017K144). Brackets were marked by hand using a scribe and caliper. This process could be simplified if aluminum brackets were used and milled in accordance to part drawings.
5. Corner brackets are attached to the motor housing plates using M6 bolts and flat T-nuts. M6 nylon locknuts are used in the final assembly SolidWorks model; this is simply a theoretical representation of the mounting.
6. Motor housing assembly and roller assembly are both attached using M6 T-nuts. The T-nuts modeled in the "8'x20' Frame assembly are only used for representative purposes.