Automated Polishing Station

Senior Design Proposal submitted to the
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Bachelor of Science

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by

Matthew Lupu

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Thesis Advisor: Amir Salehpour

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PROBLEM DEFINITION AND RESEARCH

Problem Statement

I plan to tackle the issue of polishing granite chamfers for my father's business by using an industrial robot to automate the process. The current process is done by a human using a water fed polishing grinder that leaves the user extremely wet and covered in dust. To combat this I plan to buy a second hand industrial robot from a local industrial supply auction house. This robotic cell will become a specialized area in our shop that will allow for a user to bring a rough cut granite slab ready for polishing to be chamfered and polished to a clean finish. Therefore rather than having a worker worry about tool setup and manually polishing the granite, they can cut more material on other machinery or prepare for the next job.

RESEARCH

Background of the Problem

My father's business cuts and installs granite,quartz, and other fabricated stones for residential and commercial business on a daily basis. Due to the current large workload and lack of skilled workers my father would rather have his workers focused on material movement and job preparation rather than having to polish edges. Workers are still performing the manual process of using a polishing tool that is water fed to abrasively polish the edges of stone and to leave contours that won't hurt anyone touching it. To automate this process we will have to plan out a way to bring a rough cut stone to a table where the stone can be polished around it's edge's, either the stone will be rotated to allow the robot to polish around it or have the robot will be fixed in an orientation that will allow it reach around all of the edges easily. When looking at the polishing process itself we need to weigh out the consideration of having the robot arm run 3 different polishing pads by swapping out pads between passes or find a better quality abrasive that can allow us to reach the polish we need in one pass.

This project currently has a budget of $5,000 that with estimates from online markets leaves around $1000 to $3000 for purchasing the industrial robot and the remaining funds to be used for fabrication and miscellaneous materials [1]. Looking at the time frame of completing this project; we plan to buy the industrial robot by the end of September 2022, have the fabrication/setup done by the start of the 2023 spring semester, and validation testing finalized by the start of March 2023. I anticipate using our winter break during the month of December to be able to work full time on the project as my father's shop is heated and I'll be able to start testing in day to day operations. As for staying safe during this project we will either need to look into safety stop systems that emergency stop the robot once a light curtain is broken or give the robot ample space on the shop floor so it can be taped off so workers know not to walk around it or place materials there.

Currently our process for polishing edges is done manually by a human who uses an electric grinder to slowly polish back and forth along the edges. To reach our desired surface finish we must use a 3-step polishing pad process where after an edge is polished the worker must change out the pad to the next step up in surface finish in order to smooth out the edge[2]. Aside from this whenever someone manually polishes they have to wear a waterproof apron and a mask due to the large amount of water and dust produced from the process. Therefore by automating our polishing operation we are hoping to relieve workload for our workers to be able to focus on other value added tasks while also increasing our quality control by having less variance in how the edges are polished.

Figure 1: Polishing pads

The current polishing process is very dirty and potentially hazardous to a human doing the job, with an industrial robot I plan to automate the polishing process to reduce polishing time and to allow workers to focus more on quality inspection to reduce rework when at the job site. To program the robot I am looking to use simulation software like RoboDX or Ninvidia's ISAAC Platform as well as teach pendants that could be included with the robot[3]. Since the operation involves chamfering an edge at a 45° angle along a rectangular or circular piece of granite, the travel paths of the robot should be relatively similar since the thickness of our granite is all one standard size[4]. As for the robots EOAT (End of Arm Tooling) I am planning to model and 3D print a tooling fixture that can hold the polisher or have them fabricated out of metal after testing. I hope to use this senior design project not only to gain more robotic automation experience but to also help my father's business be more efficient and less labor intensive for his workers.

State of the Art

OnRobot Sander

The OnRobot sander is a buffing and polishing electric orbital sander. Since the system is electric and doesn't require an air compressor to power it is less expensive to run and makes less noise. There are force torque sensors on the wrist of the EOAT that allow for better control of the sander's speed and thus allowing the sander to reach high quality finishes while going over complex geometries[5]. The company also claims ease of use thanks to their software being integrated easily with many robotic arm brands but also because it allows for the tool to save waypoints and path plans, making the programming easier[5]. There is no given price for this tool on OnRobot's website, but a quote is requestable and something I am inquiring about. I have bought tools for projects during my previous co-op's and my experience is that their EOAT toolings range from $5,000-$10,000 which is out of my budget.

PushCorp

PushCorp offers a robotic surface finishing system that can be integrated with any robot brand. Their special force control device allows for the robot to have consistent but adjustable force when in contact with a workpiece[6]. The claim is they have such a good active force compliance device that they can emulate human touch which provides unmatched quality and precision[6]. The systems are however pneumatically powered which for my application will cause more dust to fly around and increase cost from our personal air tanks, let alone the amount of extra complexity that is needed to be added to the robot. As high quality of a finish that the PushCorp can provide, it is not worth the complex integration in terms of controls and utilities needed. Although a price is not included and a custom solution would need to be made, this option is too much for my use case and would probably cost more in materials to make than the OnRobots sander.

ATI axially-compliant finishing tool

This sander from ATI is an axially-compliant orbital sander that runs off of adjustable air control and maintains constant axial force on a floating sindle[7]. The floating spindle will provide constant force to the work piece to adjust to geometry variance and reduce wear life on the polishing pads. Although this system is run by air it is significantly more compact than the PushCorp thus requiring less air to power it, but it also has a vacuum that can be enabled to help with cleaning dust from the granite. The EAOT tooling is compatible with most brands and also has built in software to make programming more smooth for operators to use[7]. This may be the best solution I have seen so far but a quote is needed from the manufacturer and proprietary toolings like this don't come cheap. Since this is the most compact and barebones of all the EAOT options it may be cheaper but most likely won't fit in my budget.

Applicable Standards

I will be basing my applicable standards of the ISO (International Organization for Standardization) standard requirements for robots as this is the standard that is used by many manufacturing plants and by the companies that manufacture the robots themselves. One of these standards will be ISO/TR 20218:2018 "Robotics — Safety design for industrial robot systems", this will be to ensure that my electrical and control systems are safely set-up and operating to prevent fires or memory errors in the controllers[8]. Another standard that will be important for the EOAT will be ISO 9409:2004 "Manipulating industrial robots – Mechanical interfaces", this will ensure that our sander will be safe to operate and be used with the robot arm without risk of safely dropping the sander or running it too fast and burning out the pads[8].

End User

The end user of this product will be my father and his workers that will semi-operate it. The plan is to simplify the process for the user so much that they just have to provide the robot arm with a standard cut slab of granite and it will polish it without manual labor or getting dirty/wet. Since our jobs are so similar there should be no need for the workers to need to reprogram the robot for each job and allow them to do easier, more specialized jobs in our shop.

Summary of Research

There are already several solutions that I presented that can be retro-fitted to work for my application in granite cutting but they all are too expensive for my budget. Because of this I will have to design a gripper or fixturing system that can use our polishing grinders to be an effective EOAT for an industrial robot. This will include needing to research and design an EOAT that fits our grinder and robot wrist, analysis of its strength and other attributes. A simulation of the system will be needed to validate process optimization and test different configurations.

Quality Function Deployment

Customer Features

Cost

Reliability

Ease of Use

Noise

Efficiency

Weight

Ease of Maintenance

Safety

Size

Engineering Characteristics

Air Power

Electric power

Hydraulic

Gripping Force

Polishing Force

Gripper Force

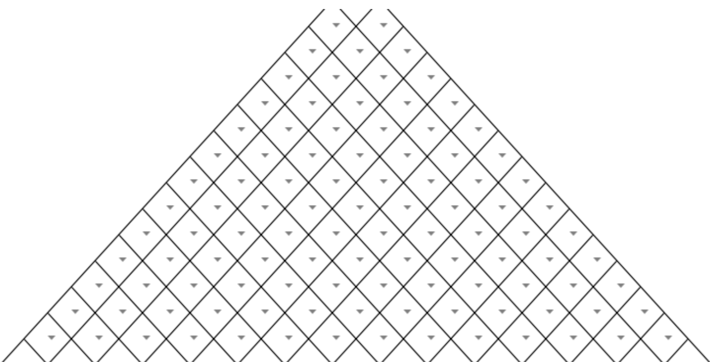
House of Quality (Overall Robot Cell Design)

Author:

Date:

Notes:

Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	X	▼	▲	X	▲										Competitive (0=Worst,					
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Air Power	Electric	Hydraulic	Gripping Force	Polishing Force	Gripper Material															
1	9	12.3	7.0	Cost	O	O	O			Θ										5	2	3	1		
2	9	12.3	7.0	Reliability	O	O	O	▲	Θ	Θ										3	5	5	5		
3	3	10.5	6.0	Ease of Use	O	O	O			O										4	3	4	3		
4	3	7.0	4.0	Noise	▲	O	O		O											3	4	4	2		
5	9	14.0	8.0	Efficiency	O	Θ	Θ	O	Θ											3	4	4	3		
6	9	8.8	5.0	Weight	O	Θ	O			Θ										3	3	3	2		
7	9	8.8	5.0	Ease of Mainetnace	▲	Θ	O													4	3	3	2		
8	9	15.8	9.0	Safety	O	Θ	Θ	Θ	Θ											3	4	3	3		
9	9	10.5	6.0	Size	Θ	Θ	Θ			O										4	4	3	2		
10																									
				Target or Limit Value						$500															
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	8	6	7	5	7	4															
				Max Relationship Value in Column	9	9	9	9	9	9															
				Weight / Importance	331.6	647.4	542.1	196.5	400.0	363.2															
				Relative Weight	13.4	26.1	21.9	7.9	16.1	14.6															

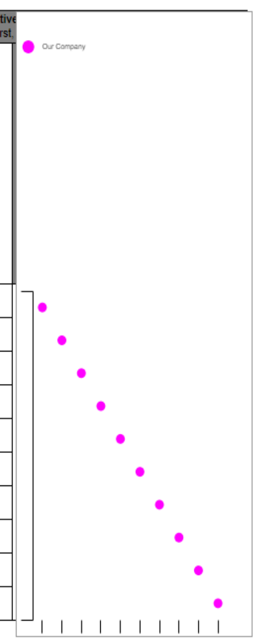


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Table 1: HOS (house of quality)

Product Objectives

Cost (12.3%)

A budget of $500 has been set to purchase material and fabricate the End of Arm Tooling, cost may go down due to a smaller robot already purchased.

Reliability (12.3%)

This is a need of the workers in order to have high repeat accuracy so they have less downtime.

Ease of Use (10.5%)

Must be intuitive for the operator to supply material and activate robot polisher, there should be little to no need for the operator program or interface with the robot to successfully manipulate the gripper

Noise (7%)

The noise this process and machine will produce are negligible compared to the rest of the noise in the shop, if needed, hearing protection can be provided to the operators.

Efficiency(14%)

The overall efficiency and cycle time of the process is critical to maintain or go faster than current manual operation in order realize benefits of automation

Weight (8.8%)

Since the polisher has a relative weight of 5-8 lbs this will reduce the amount of material that the gripper can have while being light enough for the robot to operate the process.

Ease of Maintenance (8.8%)

Maintenance of these grippers should be relatively easy to assemble and disassemble if an operator needs to or use common parts that can be easily sourced if broken.

Safety (15.8%)

The gripper should be relatively safe regardless of power method used but any of these high voltage/pressure systems will need a failsafe as backup.

Size (10.5%)

Depending on the material and its weight the size will be dependent on an optimized design large enough to hold the forces from the polisher and small enough to not inhibit the robots critical movements.

Design

Design Alternatives and Selection

To create this work cell and make it automated there will be a symbiotic relationship that the robot itself, sensors, and end of arm tooling must have in order to operate correctly. Here I make the decisions for what robot to use based on the most important criteria I determined for this project. The sensor selection will look at what sensors will be needed and how they will be integrated into the cell. For the end of arm tooling I look into several design alternatives, the mounting methods, and what material the EOAT should be made of.

Robot Selection

I based my robot selection off of the majority of inventory at my local industrial auction house.

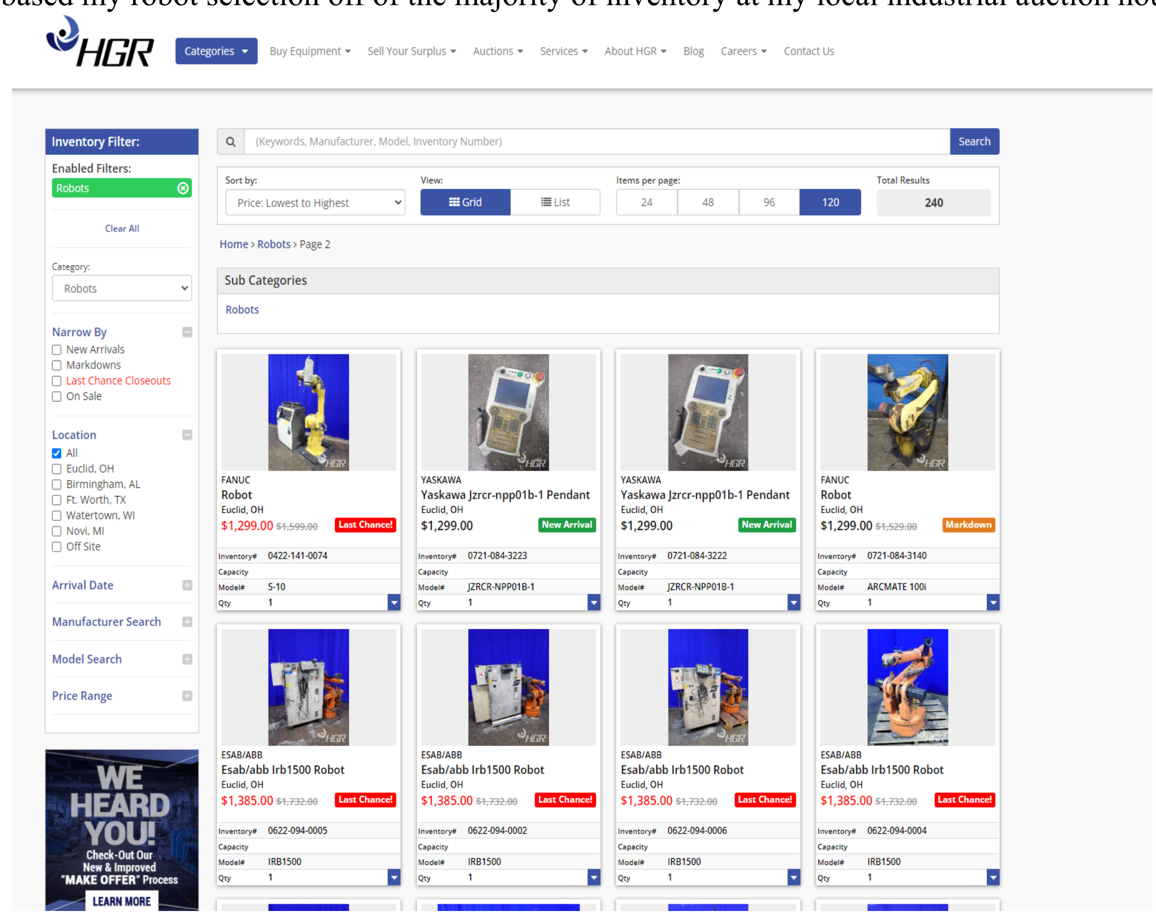


Figure 2: HGR auction page

ABB IRB 2400L

Six axes and a large work envelope make help make the ABB IRB 2400L S4C maximize efficiency to your arc welding and machine tending applications. The IRB 2400L works with a S4C, S4C+, or IRC5 controller.

With the IRB 2400L, cycle times will be shortened, and this faster production will not cause you to sacrifice any of your production quality. Consistent part quality is one of the many advantages of using the ABB IRB 2400 L. This robot is versatile enough to perform all of the functions above, while also having the ability to work in a variety of different environments. To keep the IRB 2400L at top performance, manufacturers need to keep a regular maintenance schedule, which includes using the proper grease and oil on the gears. The IRB 2400L uses Mobilgearlube X320 oil for all its axes.

For more information about the ABB IRB 2400L,
contact a Robotworx representative today at 740-251-4312.

Robot Information

Robot Specifications	Robot Motion Speed	Robot Motion Range
Axes:............. **6**	Axis 1.......**135 °/s (2.36 rad/s)**	Axis 1.....**±360°**
Payload:........ **7 kg**	Axis 2.......**135 °/s (2.36 rad/s)**	Axis 2.....**±200°**
H-Reach:....... **1800 mm**	Axis 3.......**135 °/s (2.36 rad/s)**	Axis 3.....**±125°**
Repeatability: **±0.06 mm**	Axis 4.......**310 °/s (5.41 rad/s)**	Axis 4.....**±370°**
Robot Mass: **380 kg**	Axis 5.......**310 °/s (5.41 rad/s)**	Axis 5.....**±240°**
Structure: ..... **Articulated**	Axis 6.......**310 °/s (5.41 rad/s)**	Axis 6.....**±800°**
Mounting:..... **Floor, Inverted**		

Robot Controllers

- S4C ›
- S4C+ ›
- IRC5 ›

Robot Applications

- Arc Welding ›
- Assembly ›
- Cutting ›
- Meat Processing Automation ›
- Tig Welding ›

Figure 3: ABB IRB 2400L Specifications

ABB IRB 1500

The IRB 1500 is designed for swift operation and reliability, with a handling capacity of 5 kg. The hanging variant allows for high performance when floor space is limited and a large processing area is required. The IRB 1500 is a favorite on many factory automation floors due to its fast and reliable work cycles, with low noise levels and longer intervals between routine maintenance.

Capable of arc welding, material handling, and other process, the new or used ABB IRB 1500 will benefit any factory automation line where control and accuracy are required.

For more information about the ABB IRB 1500, contact a Robotworx representative today at 740-251-4312.

Robot Information

Robot Specifications

Axes:............	**6**
Payload:........	**5 kg**
H-Reach:.......	**1450 mm**
Repeatability:	**±0.05 mm**
Robot Mass:	**350 kg**
Structure:	**Articulated**
Mounting:.....	**Floor, Inverted, Angle**

Robot Motion Speed

Robot Motion Range

Robot Controllers

S3 >

Robot Applications

- Arc Welding >
- Drilling >
- Material Handling >
- Mig Welding >
- Shielded Metal Arc Welding >
- Tig Welding >
- Welding Automation >

Figure 4: ABB IRB 1500 Specifications

Fanuc S-10

Similar to the Fanuc ARC Mate Sr, the Fanuc S-10 robot is an affordable solution to automation needs. Compact and versatile, the S-10 is ideal for applications that require precision such as dispensing and assembly. The Fanuc S-10 has six axes of motion and multiple mounting options add to the flexibility of this robot arm. A slim body allows for minimal floor space requirements.

The S-10 has many performance-enhancing features such as absolute encoder positioning and RV speed reducers on the three major axes for smooth motions at slow speeds. A direct-drive design eliminates troublesome belts, chains, and ball screws. The AC servo motors have a high power-to-weight ratio, allowing for maximum speed and torque. Integral fail-safe brakes on all 6 axes increase safety.

If you are looking to save even more costs, then consider a used Fanuc S-10 robot. The used S-10 purchased with RobotWorx includes the RobotWorx Value Package. Quality is important so all used Fanuc S-10 robots have undergone a very meticulous refurbishment process. You cannot go wrong with a new or used robot purchase with RobotWorx.

For more information, contact a RobotWorx representative today at 1-877-762-6881

Robot Specifications

Axes:	**6**
Payload:	**10kg**
H-Reach:	**1346mm**
Repeatability:	**±0.2mm**
Robot Mass:	**200kg**
Structure:	**Articulated**
Mounting:	**Floor, Inverted, Angle**

Robot Motion Speed

J1	**135 °/s (2.36 rad/s)**
J2	**90 °/s (1.57 rad/s)**
J3	**135 °/s (2.36 rad/s)**
J4	**240 °/s (4.19 rad/s)**
J5	**240 °/s (4.19 rad/s)**
J6	**400 °/s (6.98 rad/s)**

Robot Motion Range

J1	**±300°**
J2	**±135°**
J3	**±265°**
J4	**±380°**
J5	**±280°**
J6	**±540°**

Applications

- Arc Welding Robots
- Assembly Robots
- Dispensing Robots
- Drilling Robots
- Machine Loading Robots
- Material Handling Robots

Figure 5: Fanuc S-10 Specifications

Robot Selection Weight Rating

By using the weight rating method I have determined that the Fanuc S-10 will be the best overall option based on my needed robot criteria mainly focussing on lift, reach, power source, and cost. The S-10 will also help save on money as it is the cheapest of the group but may cause problems along the line since it's also the oldest and least likely to be supported by the OEM.

Criteria	Weight	ABB IRB 2400	Rating (1-4)	Weighted Rating
Configuration	5%	6-axis articulated	4	0.2
Repeatability	10%	0.06mm	3	0.3
Lift capacity	25%	12kg	3	0.75
Reach	25%	1800mm	4	1
Power Source	20%	480V 3 Phase	3	0.6
Cost	15%	$4,500	1	0.15
				3

Criteria	Weight	ABB IRB 1500	Rating (1-4)	Weighted Rating
Configuration	5%	6-axis articulated	4	0.2
Repeatability	10%	0.05mm	3	0.3
Lift capacity	25%	5kg	2	0.5
Reach	25%	1450mm	3	0.75
Power Source	20%	380V 3 Phase	2	0.4
Cost	15%	$1,385	3	0.45
	100%			2.6

Criteria	Weight	Fanuc S-10	Rating (1-4)	Weighted Rating
Configuration	5%	6-axis articulated	4	0.2
Repeatability	10%	0.2mm	2	0.2
Lift capacity	25%	10kg	3	0.75
Reach	25%	1346mm	3	0.75
Power Source	20%	480V 3Phase	3	0.6
Cost	15%	$1,299	4	0.6
	100%			3.1

Table 2: Robot weight rating

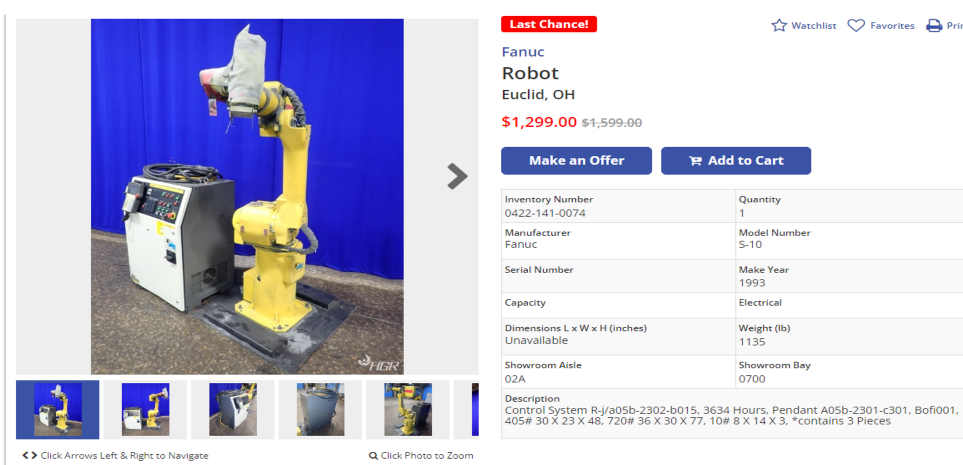


Figure 6: Fanuc S-10 Listing

EOAT Design Process

Gripper tooling shape and size

Here I use a caliper to take measurements of a common angle grinder and compare the characteristics of choosing how the gripper will work. In my research on how to power this EOAT I decided on keeping it still electric but updating the motor aspect of it to be more compact by using a hybrid stepper motor so not only are we saving on weight but also now have the option to control the speed of the motor.

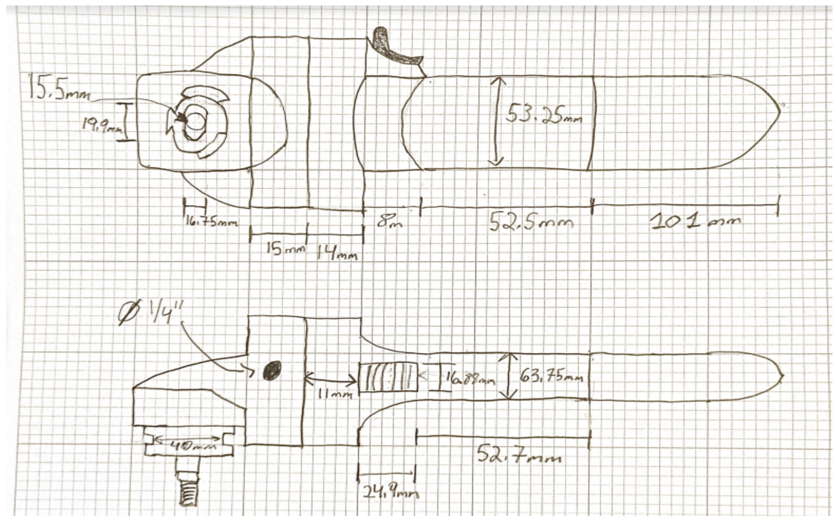


Figure 7: Polishing grinder caliper measurements

Table 3: EOAT powering method

Hydraulic	
Strengths	Weaknesses
Good for large robots/heavy payloads	Leaking
Highest power/weight ratio	Requires hydraulic system setup
No reduction gear needed	Oil viscosity changes with temperature
Large range of working speeds	Low Compliance
Pneumatic	
Strengths	Weaknesses
Reliable	Noise
Parts are common	Requires pressurized air setup
No leaks/sparks	Lowest power to weight ratio
Inexpensive and simple	Very low stiffness, may result inaccurate response
Electric	
Strengths	Weaknesses
High precision, better control	Needs reduction gears
No leaking	May require high voltage system
Reliable	Low stiffness
Can be used with any size robot	Motors need brakes for any joints not powered
AC motors	DC Motors
More power/torque	Energy efficient
Dissipates heat more effciently	Speed control through varying current in winding's
No brushes/less maintenance	Max torque is developed at zero angular velocity
Speed control through varying frequency	Lower life expectancy
Work with higher currents without damage	Can be powered by batteries

Figure 8: Makita 7.5 amp grinder

Concepts Drawings

Easy and simple design, made to mimic the simple outer diameter of our common polishers with slight chamfers around the edges for tolerance allowances to allow a secure grip around the handle of a polisher. The rounded part on the top acts as a spacer for the head of the polisher to keep it from sliding down since the other two tabs have the contour of the polisher but allow it to slide too close to the tabs.

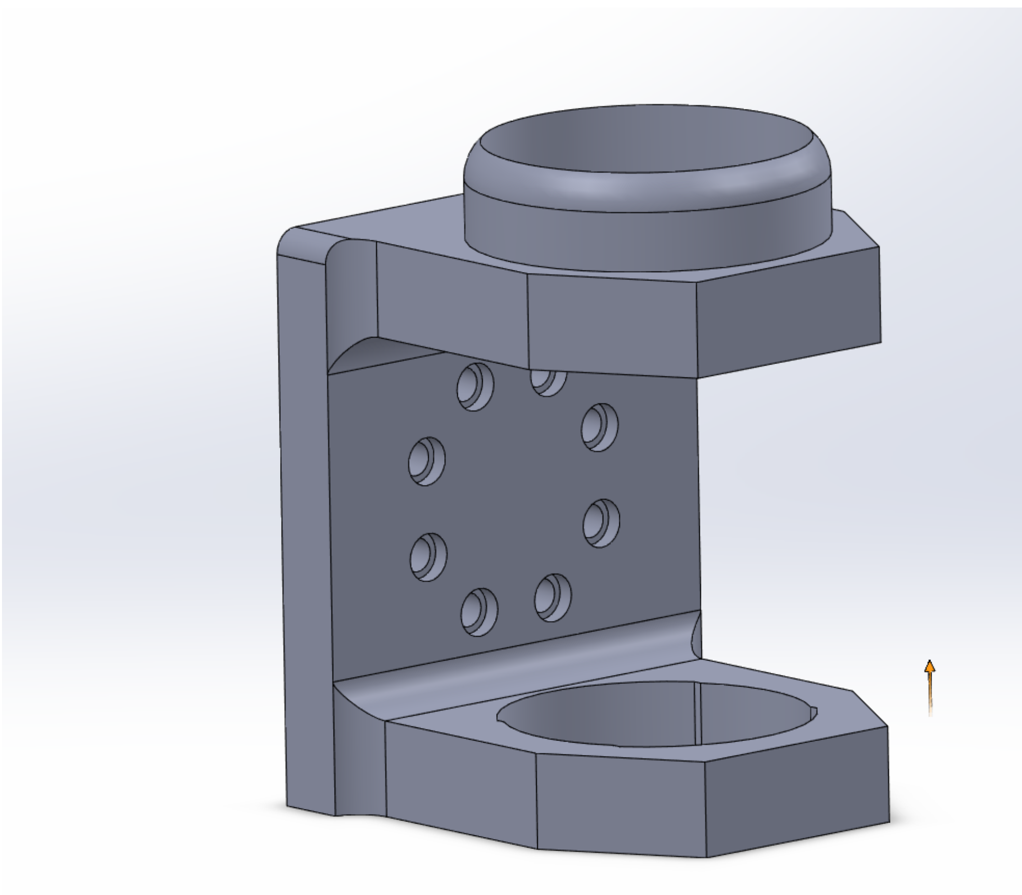


Figure 9: EOAT initial design

This bracket design is made to connect the head of a standard angle grinder with a stepper motor while removing the original middle section of the grinder to make it more compact. With this design I am able to add a mounting fixture on the top of the bracket where it is able to connect with a standard ISO robot tool mount ranging from 30mm to 63mm. This option may help in reducing weight but I also lose overall length of the tool thus making the overall reach of the robot slightly smaller.

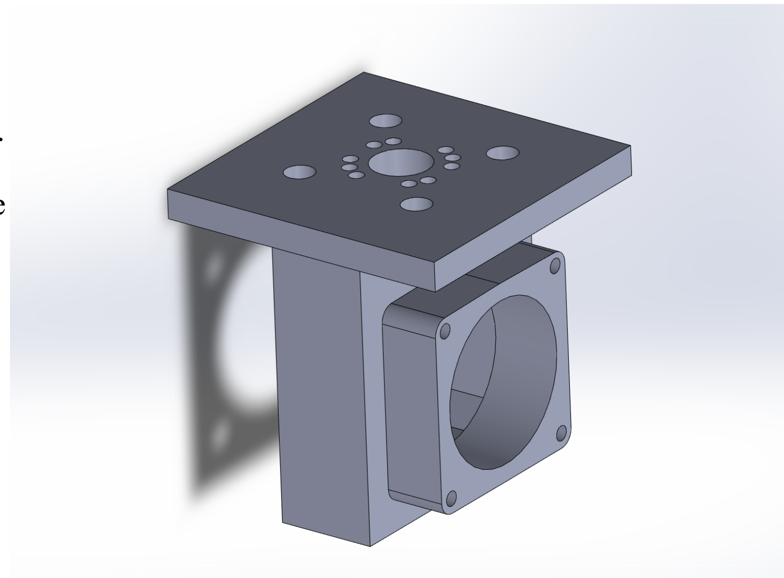


Figure 10: EOAT design 2

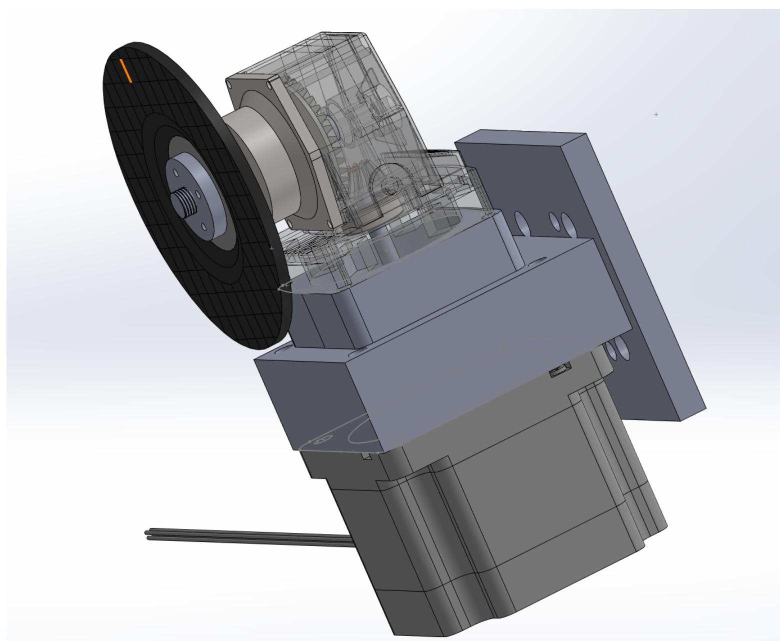


Figure 11: Design 2 assembly

Final Design

For my final design I went back to the initial design to use the original polisher assembly but rather than having the round feature on the top I changed it to accommodate the power switch. This came about during testing of initial design where the fixture would hold the polisher during operation fine but randomly due to vibrations the polisher would switch off. To counteract this I removed the rounded top and added a pocket for the power switch on our makita tools to keep the switch more isolated from switching off due to vibrations. This managed to solve the problem and cut down on the overall weight of the fixture.

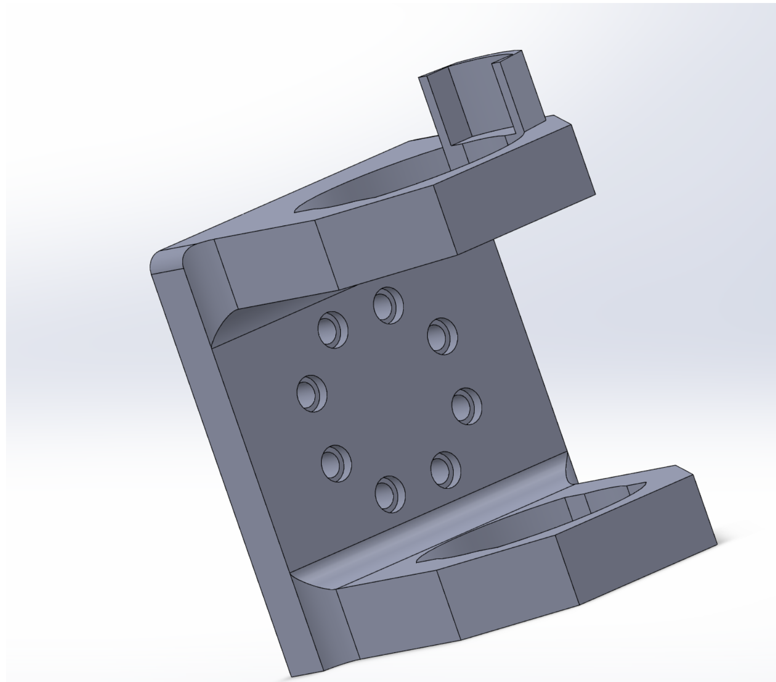


Figure 12: EOAT design 3

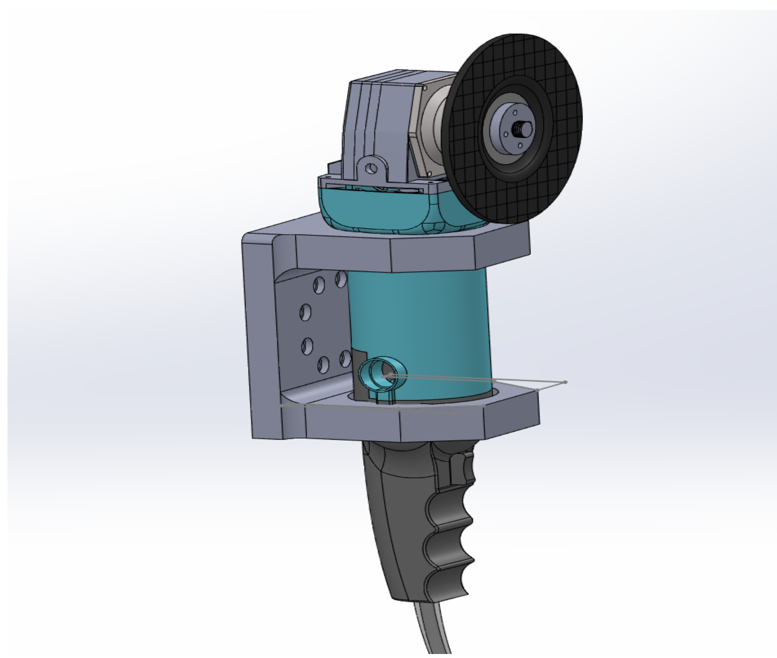


Figure 13: Design 3 assembly

Finite Element Analysis

To determine what material to use I ran an FEA for the bracket based on 4 materials: Carbon Fiber ABS, AISI 1020 Steel cold rolled, Aluminum Alloy 3003, and PET plastic. I ran the stress analysis by using the top part of the bracket where it connects with the tooling mount as the fixture and applied a 100 Newton force to the front of the bracket where it connects with the grinder head to simulate the stress of the bracket while under load. Seen in the figure below a test comparison on the stresses applied in this configuration with none of the materials coming within range of their yield strength by at least $2.00 * 10^2\ N/m^2$. Same goes when running a similar test on displacement with none of the materials being displaced more than $7.00 * 10^{-3}$ mm, therefore I can justify any of the materials tested.

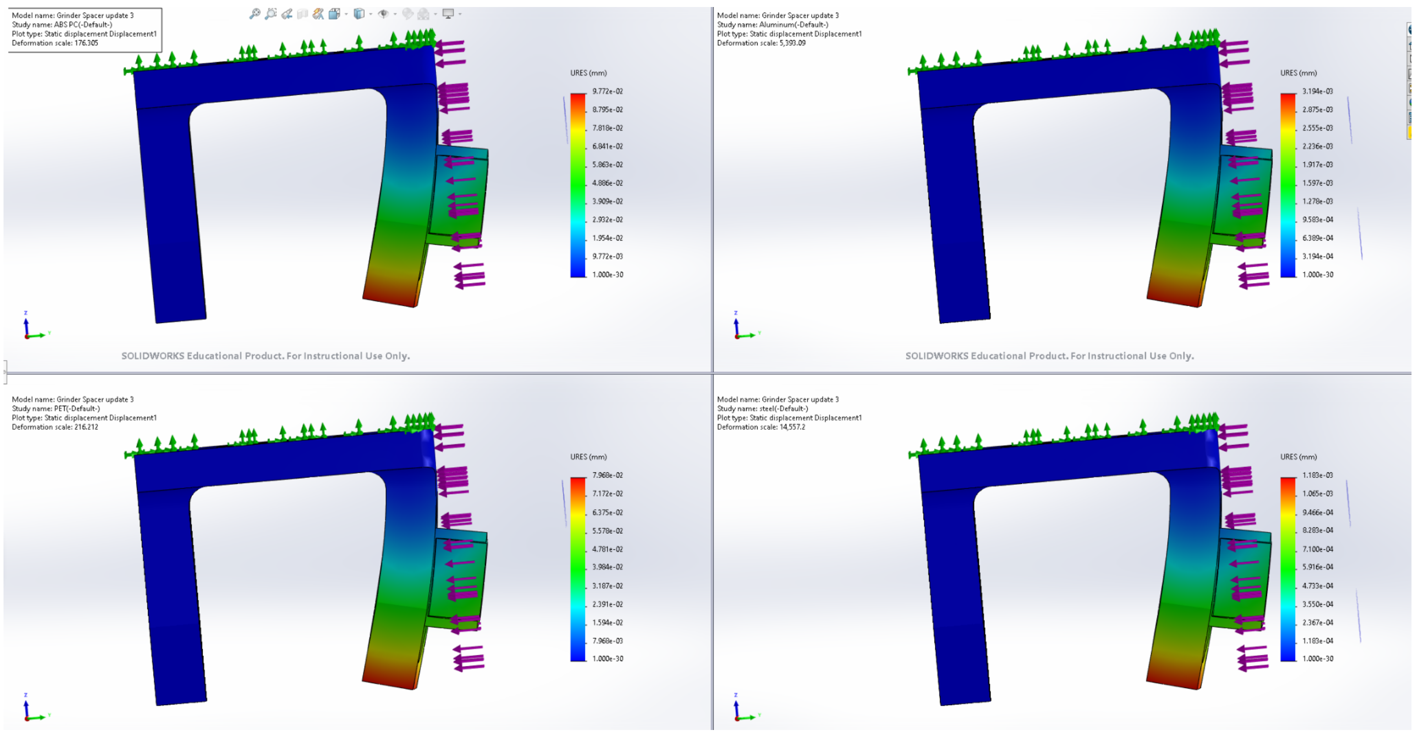


Figure 14: FEA multi material comparison

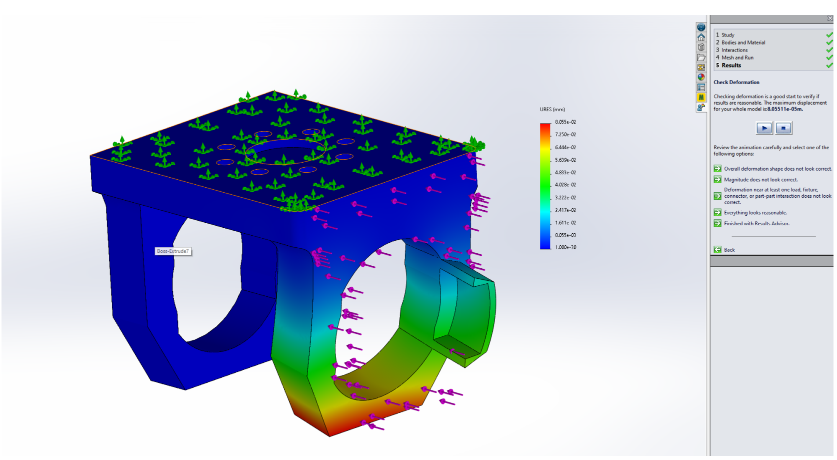


Figure 15: FEA displacement analysis

Fabrication/Assembly

EOAT

To make my final decision on what material to use for the bracket I decided to run a cost estimate for maching it out of steel and 3D printing with the PET. For machining the cost came out around $320 whereas for 3D printing I can print about 4 of these brackets with 1 kg of material which only costs me about $45. I plan to 3D print this myself as I have a printer cable of printing this material and will be sourcing the filament from Mcmastercarr or Microcenter.

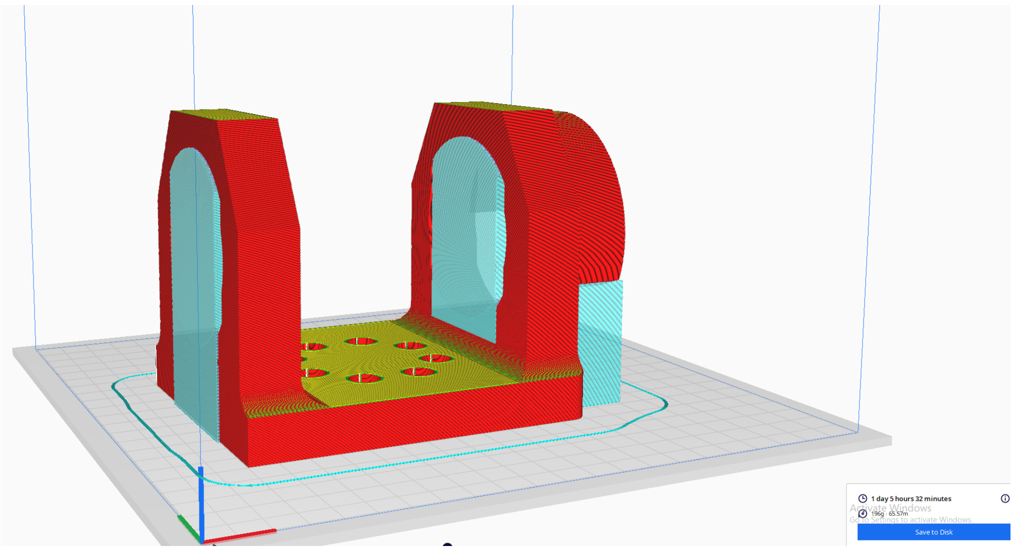


Figure 16: EOAT 3D printing fabrication

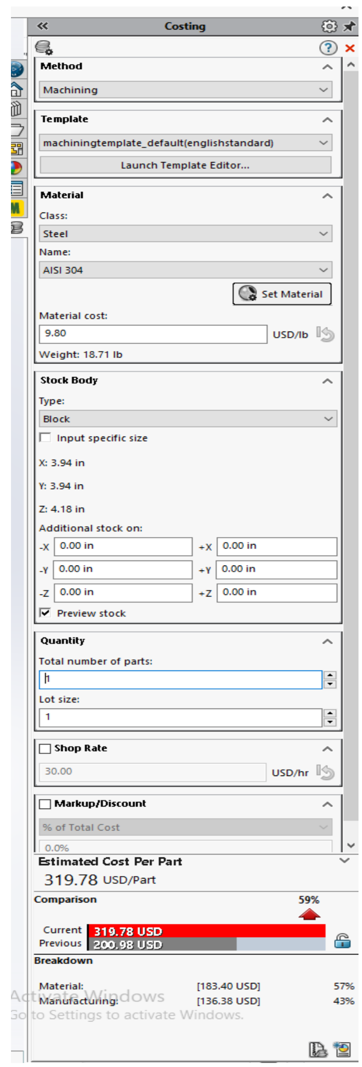


Figure 17: EOAT steel fabrication cost

Figure 18: Assembly of EOAT & S-10

Cell Design Layout

Two alternative designs were made after measuring the robot in relation to a wall where the electrical connections will be placed. Measurements of the polishing tables were also made since they are all constructed the same and can be used interchangeably. The largest slab of granite that this robot will have to fit in its work envelope is 6ft by 4tf and can range from any shape smaller than that. Work cell generated in RoboDK with model of EOAT for simulation of polishing

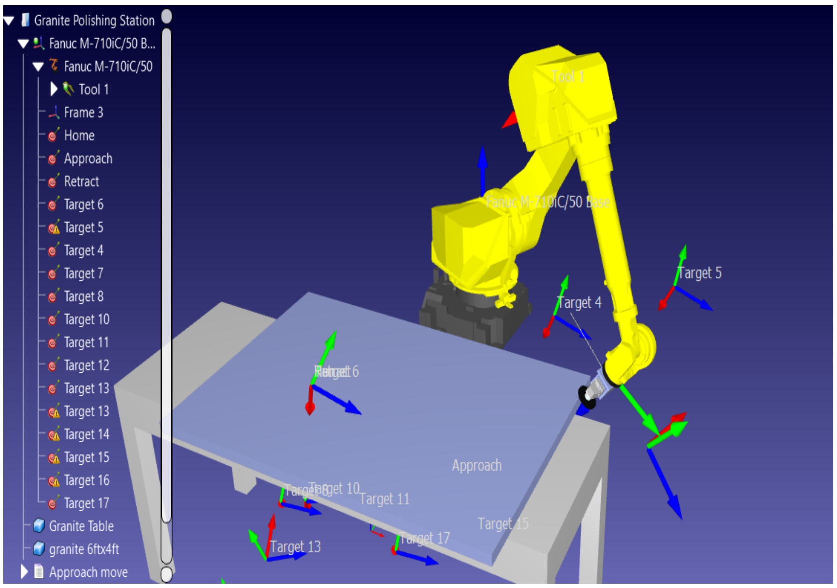


Figure 19: Robo DK simulation

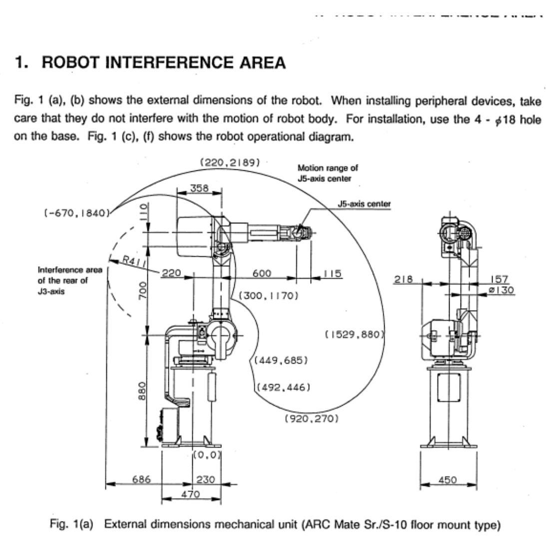


Figure 20: Robot interference area

Work Cell Analysis

RoboDK estimates my cycle time to be roughly 45 seconds, and with an estimated time of a minute to move the granite to and away from the robot, we can base the total cycle time at 165 seconds. Now using an eight hour shift production with 80% efficiency we get a production rate of 139.63 units/shift. When it comes to maintenance there will be a need to change out abrasive pads on the grinder for when they wear down, aside from yearly maintenance on the robot there should be no other task.

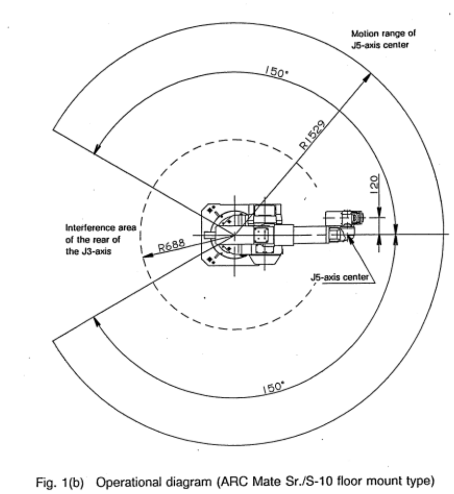


Figure 21: Robot operational area

Simulation

https://drive.google.com/file/d/1vy5aTMqnP2N3D3leEXlRQU6Lg28kLPlR/view?usp=sharing

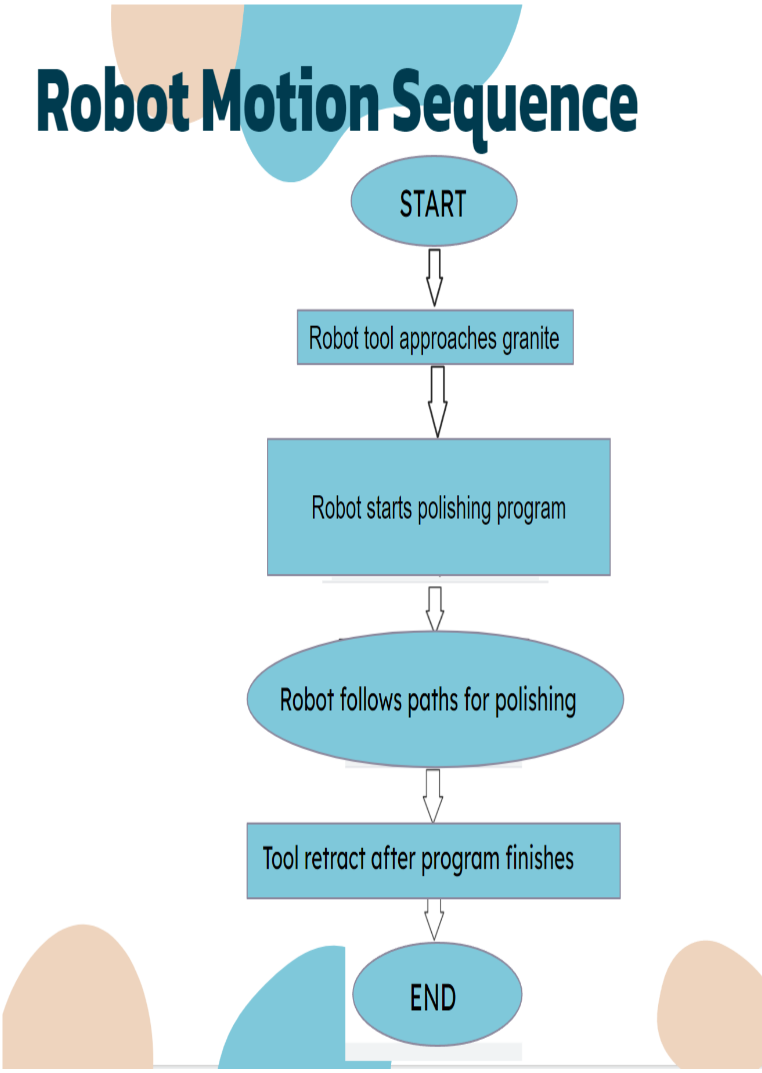


Figure 22: Robot motion sequence

Testing Method

I plan to test this simulation by using the g code generated by RoboDK to run the path program.If this doesn't work due to possible incompatibility issues then I will use the teach pendant that comes with the robot to manually guide the robot through the working positions. To test out the design of the grinder bracket I will first 3D print it with material I have already to refine the fitment if needed with the motor side. To test out the capability of polishing I plan to use scrap pieces of stone with natural edges for testing and comparing them to manually polished edges.

Project Management

Schedule

Dates	Milestones	Date Completed
10/20/22	3D print concept prototypes	10/23/22
11/1/22	Purchase or be in process of buying robot	1/2/23
11/10/22	Complete program simulation and EOAT design	11/15/22
12/6/22	Senior Design 2 Presentation	12/6/22
12/8/22 - 1/8/2023	Begin fabrication and assembly of EOAT and Robot cell	2/20/23
12/8/22 - 1/8/2023	Program robot paths without tool	3/31/23
12/8/22 - 1/8/2023	Add EOAT to robot and optimize design	4/15/23
4/6/23	Tech Expo	4/6/23
3/1/23	Refine and optimize the robots program and cycle time	5/1/23

Table 4: Project Timeline

Project Budget Limit

The budget for this project has a tentative limit of $5,000 and has been set by my father, I may need to go over budget if things get overly complicated. As of right now based on my references my estimated bill of materials should be around $3,341 depending on what robot I can get at a good price from auction.

Proposed Cost	**Actual Cost**
Fanuc S-10 Robot - $1,300	**$1,100**
Transformer - $700	**$700**
Electrical / Safety Shut off - $500	**$320**
Teach Pendant - $750	**$500**
Filament - $56	**$45**
Pick and Place Robot - $35	**$35**
Total - $3,341	**Total - $2700**

Table 5: Project Budget

Installation

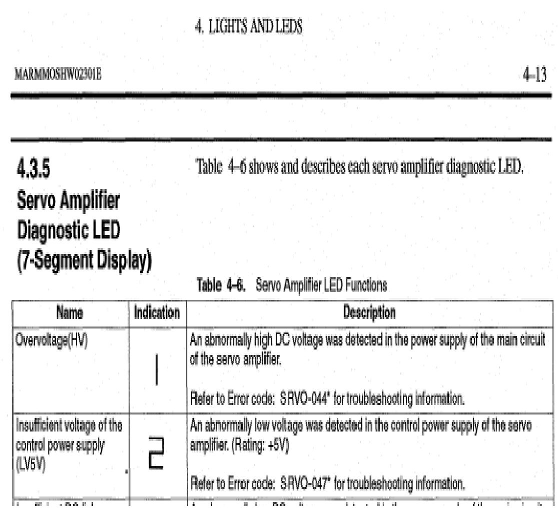
Figure 23: Hooking robot up to electrical

Upon receiving the electrical equipment and bringing the robot to our shop I began helping my electrician in connecting our 208 volt electrical service to the step up transformer in order to power the robot with as close as 480 volts possible. After completing all the wiring we were able to power up the motion controller and confirm from the transformer to the controller that 466 volts was present. The motion controller at the time didn't have a teach pendant to show the fault errors in the controller so I was only able to troubleshoot based off of the servo amplifiers inside of the controller.

Figure 24: Step up transformer

Figure 25: Safety shut off

Figure 26: Servo amplifier error LED



4. LIGHTS AND LEDS

MARMMOSHW02301E 4–13

4.3.5 Servo Amplifier Diagnostic LED (7-Segment Display)

Table 4–6 shows and describes each servo amplifier diagnostic LED.

Table 4–6. Servo Amplifier LED Functions

Name	Indication	Description
Overvoltage(HV)	1	An abnormally high DC voltage was detected in the power supply of the main circuit of the servo amplifier. Refer to Error code: SRVO-044" for troubleshooting information.
Insufficient voltage of the control power supply (LV5V)	2	An abnormally low voltage was detected in the control power supply of the servo amplifier. (Rating: +5V) Refer to Error code: SRVO-047" for troubleshooting information.

Figure 27: Fanuc LED diagnostic

Error Code Troubleshooting

To see the error codes in the controller I had to buy a teaching pendant which also aided me in calibrating and simply programming the robot. My first error to fix was the dead batteries in the base of the robot which consisted of replacing 4 D-cell batteries. Once resolved I had to do a "fake" calibration of the robot in order to clear the related error while still not being able to jog any aspect of the robot. With all this I still had an error relating to a deadman switch / emergency stop button being triggered even if I had my finger on a deadman switch which should allow operation of the robot. After some time I managed to get support from Fanuc with all of the documentation I would need and advice on how to clear this emergency stop issue. From inside the controller I had to jump the connection between two terminals corresponding to the external emergency stop as it seemed that it had been connected to an actual E-stop button but was no longer connected. This resolved all of my errors and I was then able to jog each axis of the robot into position in order to calibrate it to its true zero position.

Figure 28: Robot backup batteries

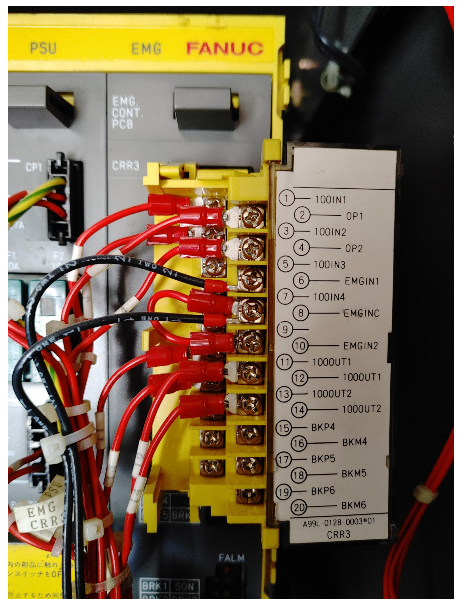


Figure 29: Emergency PCB wiring

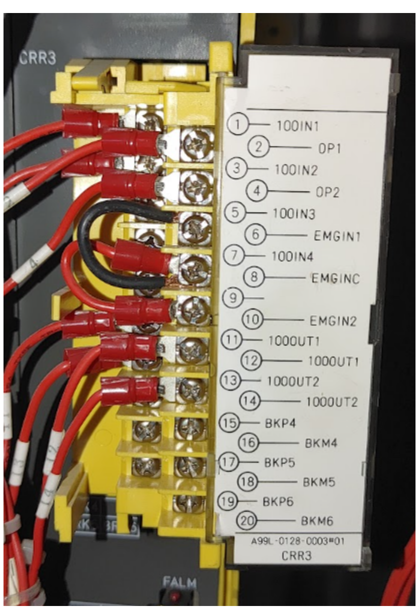


Figure 30: Updated emergency stop wiring

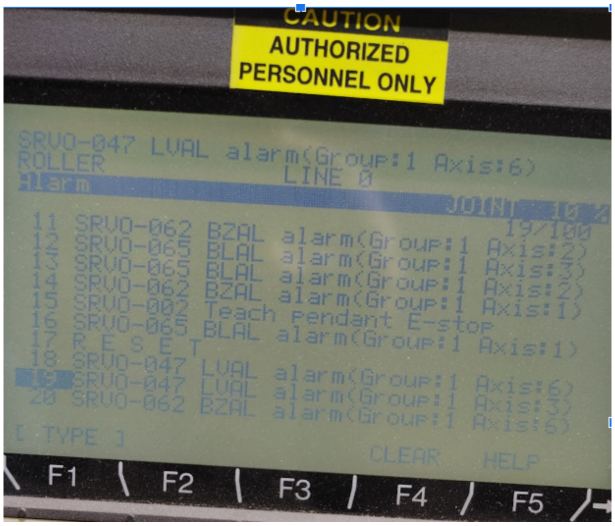


Figure 31: Error log before battery change

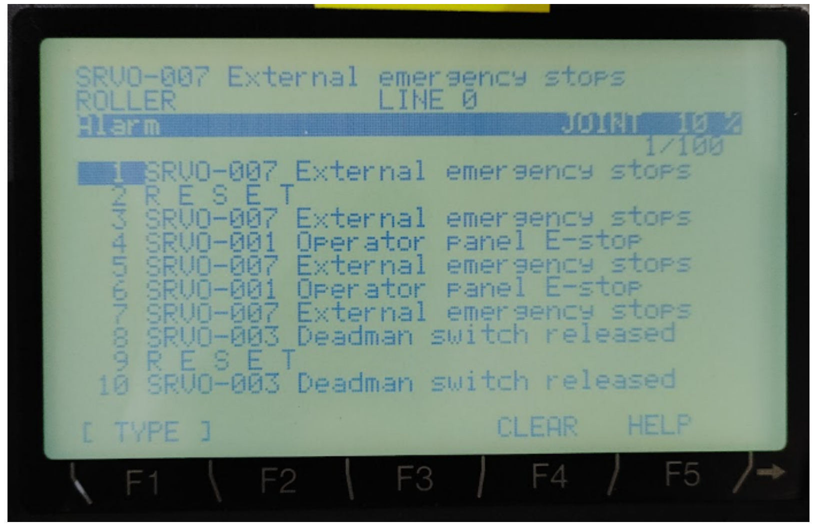


Figure 32: Error long after battery change

Figure 33: Initial robot movements after error fixing

Results

Once I had the EOAT and robot ready I was able to program the robot to take linear paths back and forth along a 6 foot length of granite to test the polishing efficiency. Based on examples we had in the shop done with manual polishing we were able to produce results near if not better than with the manual process. While the polishing grinder has an adjustable speed control we left it around 4000 rpm as this is what we and most of the industry uses, with this I had to fine tune the movement speed of the robot when moving linearly to match that of a human. After some trial and error I was able to speed up the robot's linear movement speed from 100 mm/sec to 400 mm/sec without any change to surface finish or edge symmetry. I have also run tests polishing the side lengths on the far side of the robot with a 6ft x 4ft slab of granite, thus showing that the robot can successfully operate at the maximum size limits of slabs it would need to polish. I have yet to polishing all four sides of a slab of granite as I am still learning to condense my program code into fewer lines of code since at this point the amount of code I have for polishing half of a slab already takes up three quarters of the available space I have in memory to write the full program. Although I haven’t been able to run a full slab yet I have had good results in cycle time for completing half of a slab at 2 minutes for the robot which compared to a human takes about 15 mins total or 7.5 minutes per half, thus showing an almost 4 times decrease in cycle time for this operation.

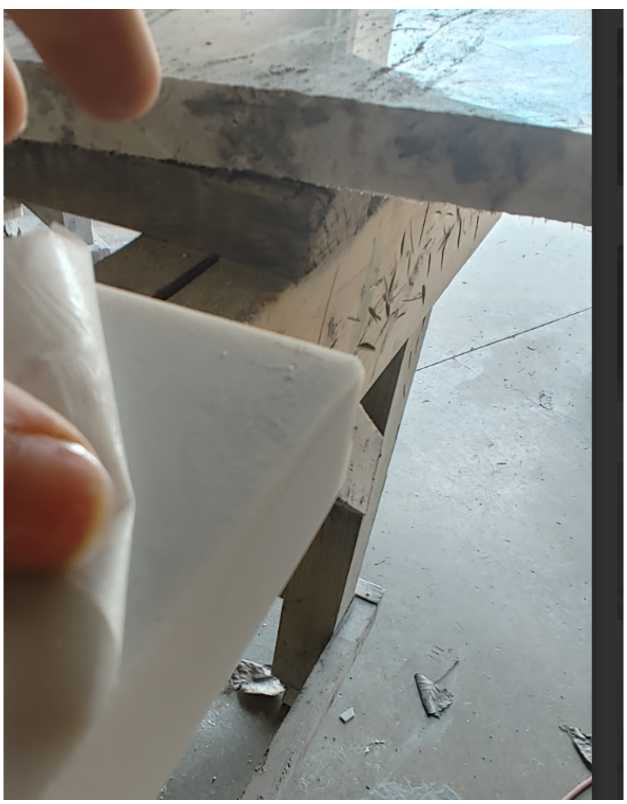


Figure 34: Pre polished edge

Figure 35: Polished edge

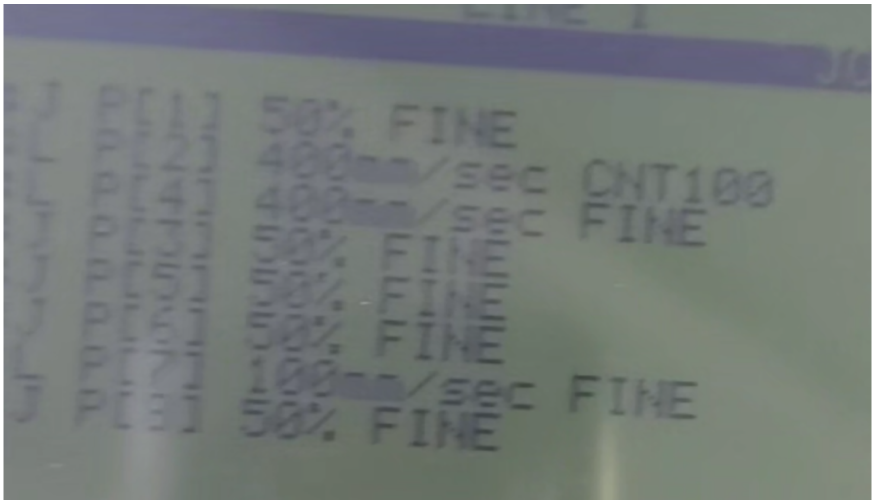


Figure 36: Teach pendant 2 sided polishing program

Initial Polishing Test video

https://drive.google.com/file/d/1HQhVFCzGzTO_y8poUKBnS5xxQiSN7Gpx/view?usp=share_link

Polishing with corner movement

https://drive.google.com/file/d/1KAxFG2ItSnqJ-SfjgVdvCT1kd0XOjghk/view?usp=share_link

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