Design for Manufacturing, Reliability, and Economics Report

Team No. 19

Construction Marking Robot

Members:

Kelsey Howard (knh12d)

Justin Gibbs (jrg13f)

Brandon Roberts (bdr12)

Derrick Portis (dp11d)

Christian Baez (cob11b)

Advisor: Dr. Nikhil Gupta

Sponsor: PSBI – Mark Winger

Instructor: Dr. Nikhil Gupta

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1. Design for Manufacturing

1.1 Assembly Time

The construction marking robot's assembly process first began with the Pioneer 2-DX robot which was provided by CISCOR. Since this robot was provided preassembled with the LiDar mounted, this portion of the assembly time can be considered virtually zero. For the gantry, the team order two C-Beam linear actuator bundles from Open Builds which included the extruded rails, lead screw, stepper motor, mounting platform, and all necessary spacers, bolts, and nuts. While the bundle included all of the parts necessary to construct the linear actuators, assembly instructions were not included, so it took about 4 hours to fully assemble both linear actuators after receiving the parts. Most of that time was due to having to figure out how to assemble the first actuator; most likely it would take about an hour at most to assemble each actuator for someone who already knows how to assemble it. In order to complete the gantry, the two linear actuators needed to be mounted together and then to the robot. In order to do this, brackets were first machined from angle iron and then attached to the platform of the first linear actuator and to the t-slot nuts inserted into the rails of the second actuator. After this, another set of larger brackets were fabricated for mounting the gantry to the robot; four holes were made in the robot's mounting platform for the mounting points of the bracket with the other end of the brackets being bolted to t-slot nuts in the side of the first linear actuator. This whole process took about six hours including the machining of the brackets. After testing the gantry, another two hours were given to slight modifications such as milling and filing down edges of the extruded rails that were causing parts to scrape and therefore not move as smoothly. This assembly was decently shorter than originally anticipated, but this is mainly due to design changes made with the intent to speed up the process and due to having direct access to the machine shop rather than having to wait for it to be manufactured.

The marker holder took around 5 hours total to create on Creo Parametric. It then took a little over 30 hours to be printed from a 3D printer.

1.2 Components

Counting the Pioneer 2-DX with the LiDar as a single part, since it was provided and is therefore not itself assembled part of the assembly process, there are a total of 149 parts that make up the prototype, not including the robotic total station. Each linear actuator bundle contains 42 parts including every bolt, washer, and nut, a total of four pieces of angle iron along with 4 pieces of 1/16th inch aluminum sheet were used as mounting brackets for the gantry, and 16 bolts, 8 t-slot nuts, and 4 lock nuts were used to fasten the gantry assembly together and to the robot. This design cannot really be simplified into fewer components, but it could be modified so the linear actuators were lighter. However, for future work, the design's complexity should be increased to guarantee more accurate results. While the current version of the prototype can be assembled much faster which leads to more time for testing the other crucial components, additional error arises due to the fact that the second linear actuator is effectively hanging off the end of the robot. To rectify this, it would be appropriate and necessary to add a support system for the actuator, most likely out of extruded rails, a passive linear component such as a shaft with a bearing to support the moving end, and a caster wheel to support the overall structure. Done correctly, this would limit the tilt in the second actuator as well as the unnecessary movement the system experiences while moving. The marker holder is comprised of 6 parts: the outer casing, the revolver, the stepper motor, and three sharpie markers.

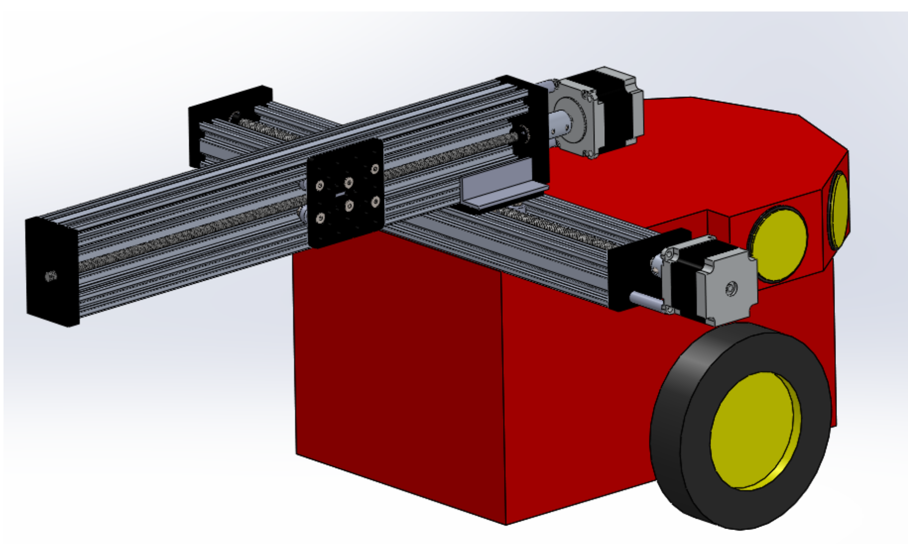

Figure 1: Assembled View

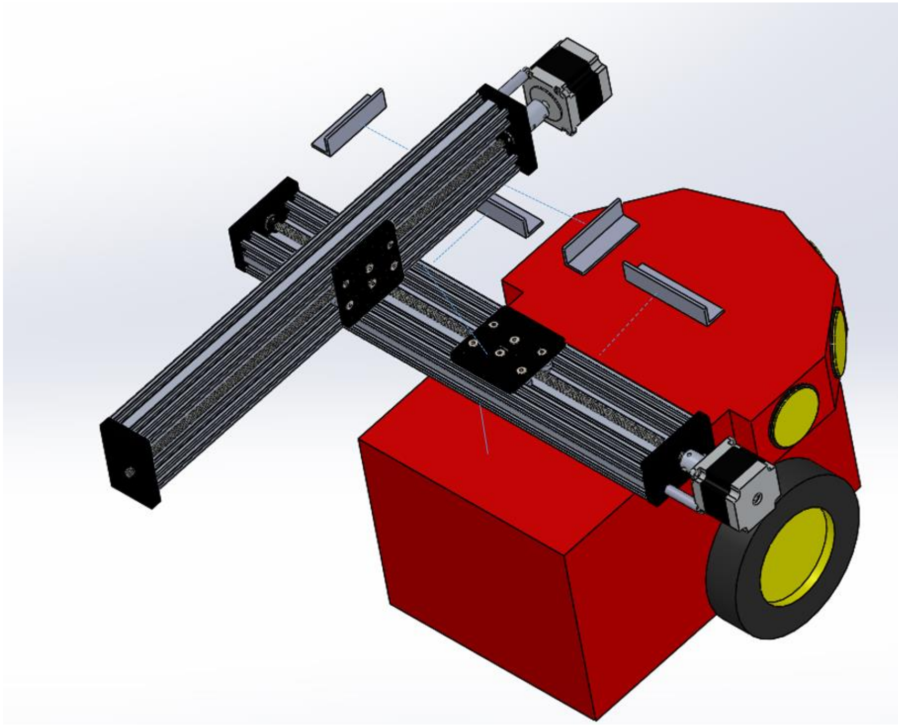

Figure 2: Exploded View

2. Design for Reliability

Reliability has become more important in the recent century than it ever has before. Now that mechanical, electrical, and computer systems are more prevalent, designing for reliability has been incorporated into the design process in order to save time and money, and increase safety. There are many different types of reliability ranging from mechanical and software to human and life cycle reliability. All the different types of reliability have certain methods to follow to optimize the product or service in respect to reliability. A few of these methods were utilized in the design of the construction marking robot.

In order for a product to be worthy it must hit the right market at the right time with the right price. Even if all of these criteria are met, if the product or service is unreliable, it will fail. The process required to make a product or service reliable is very iterative in nature, first conceptually and then experimentally. The design process is the most important step of the product life cycle as it rules how the rest of the product life will live out. Throughout the design process the team held multiple meetings to ensure that everyone was on the same page and agreed on the movement of the project. There were also major meetings held with advisors and sponsors in order to ensure that the team was moving in a customer desired direction as well as are approaching problems in the correct manner to satisfy the customer and sponsor simultaneously.

The prototype developed by the team is nearly done and some testing has already taken place. The testing has already identified a few reliability concerns to the team. The construction marking robot is only a proof of concept and was designed to help identify some major conceptual flaws with the idea of marking construction lines using an autonomous robot. There have only been a few tests done thus far and provided promising results as to a successful final product or service. The more test that will be run, the more data and information can be processed by the team to ensure success.

One of the major components that would be affected by multiple uses would be the linear guide rails. Due to their nature of moving a platform using a screw driven system, the parts are expected to wear. The construction site is not a clean place and the dirty/hazardous environment will not help contribute to the longevity of the product. One solution to extending the life of the linear guide rails would be to add dust covers and covers over the bearings. This would help prevent dirt and debris from accelerating the wear process. The longer the life of the product, the more profitable the product or service is. The dust covers and bearings are more of an initial cost and it would be the design team's job to make the decision whether or not the longevity is worth the extra cost.

Due to the nature of the construction marking robot project being a very integrative project, many things needed to be customized. Customization is not cheap but allows room for the design team to implement their own level of reliability into the design of the product. One major thing focused on be the teams was the ease of use. The easier the product is to use, the less training is needed to use the product or service. More complexity went into the design to allow for a seamless interaction with the customer and the robot. This seamless interaction would seem more appealing to the customer if a competitor would appear in the market.

One situation in which designing for reliability was considered greatly by the team was the mounting of the gantry system onto the robotic platform. There were multiple ways in which the gantry could have been mounted. Some methods included castor wheels while other methods were more balanced and did not need the extra support/parts of the castor wheel. The team met with a fellow student to bring in his expertise of mounting to the teams design. The student decided that in this case, simpler is better. Instead of designing multiple mounting brackets and extra guide rails, the team directly mounted the gantry onto the robot as seen in Figure 1. This method of mounting the gantry to the robotic platform is not the most reliable method for joining the two but with time and money constraints the teams did what was necessary and correct in the situation at hand. FEA was done in order to ensure that the gantry could support the weight and forces that maybe experienced while on the job. The mounting style seen here will see a lot of vibrations which can speed up the wear process as well as corrupt electronics mounted on board. The vibrations could also cause some of the marks that are being

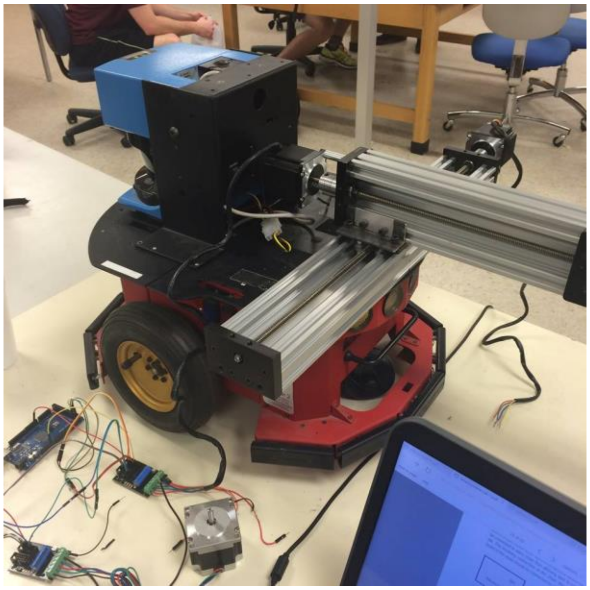

Figure 3: Construction Marking Robot

made to be off target and therefore cause error in the marking which is what the entire project is aimed at minimizing.

Some other focus points for the team are things such as robot reliability, human error, and maintenance. The robot must be reliable because there could be the possibility of humans being on the construction site during the operation. The robot weighs nearly 50 pounds and could easily hurt someone if it were to run into someone’s ankle and or fall from a structure onto a hard hat. Human error could affect the way in which the lines are to be laid out. If the robot and robotic total station are not set up correctly, the lines which are drawn on the ground could be off and/ or not accurate. Without these accurate lines, the contractors would not be able to finish the construction project safely. Walls would not be in the correct places and some plumbing maybe hanging outside of walls or even ceilings. Maintenance would be key in many aspects ranging from the cleanliness of the construction site to the up keep and cleanliness of the robot itself. It would be within the training of the operator as to the cleanliness standards for the robot as well as the construction site.

Being that the construction marking robot project will be continued for another year, this year’s prototype will give major insight into some problems that maybe encountered in the future but are unforeseen. By following the design process and keeping the reliability of the product in mind, the design team has the potential to create a great product that could revolutionize the construction industry and the way in which contractor communicate with each other as well as save time and money while doing it. This introduction of new technology into the construction industry will build a better relationship between it and the people in the field who will be using it.

3. Design for Economics

The entirety of the gantry system for the construction marking robot cost $1,536.9. With a budget of $2,500, this comes out to be a little over 60% of the total budget. The majority of this cost is comprised in the linear guide rails and the batteries. The linear guide rails cost $124.45 each, with a total of $248.90 for the two necessary to construct the gantry system. The three LiPo batteries purchased cost $199.99 each, with a total of $599.97, and the charger for the batteries cost $119.99. Figure 2 and Table 1 show the complete breakdown of the budget and the cost of individual parts in the prototype.

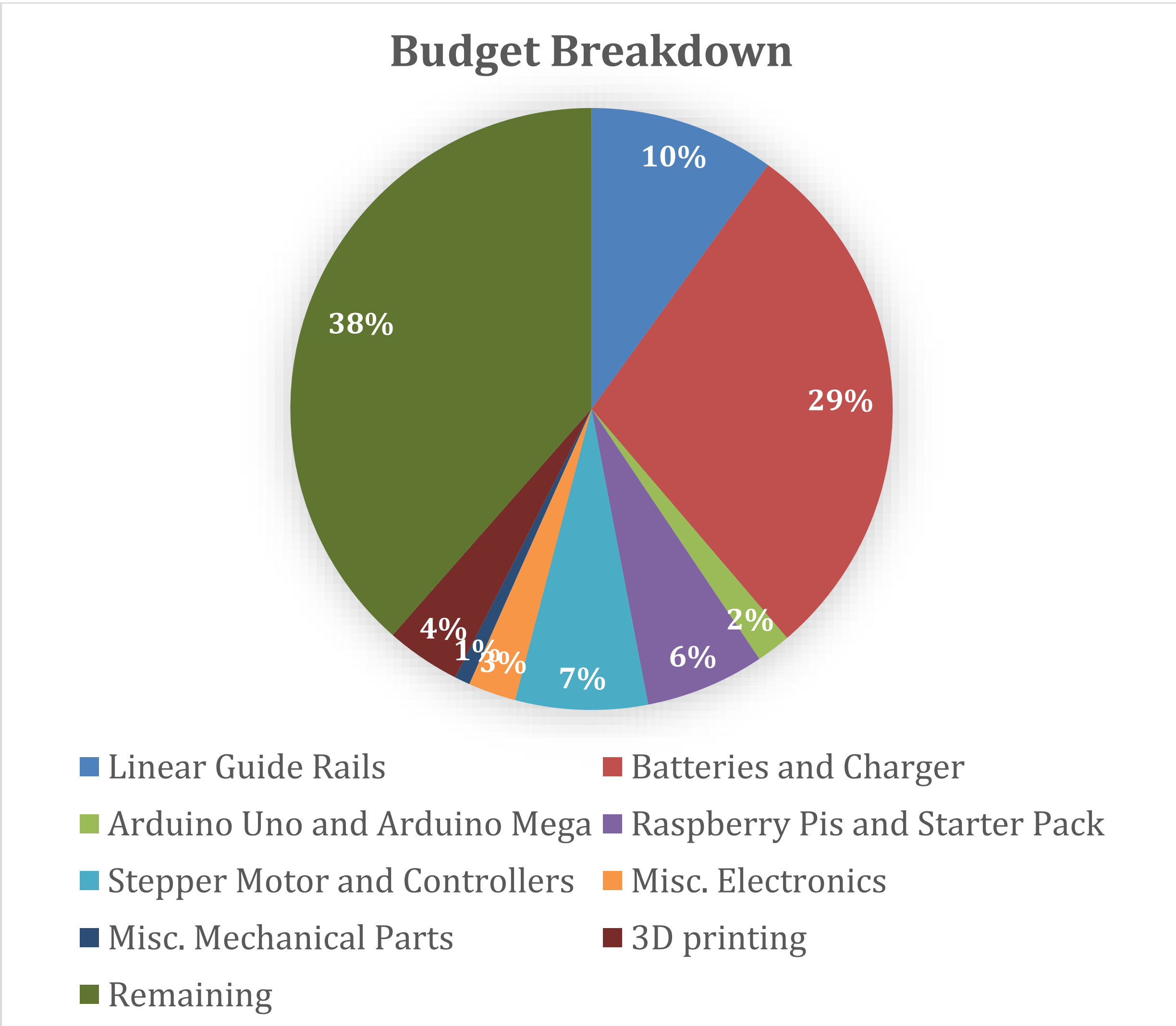

Figure 4: Breakdown of Budget

Table 1: Component Costs

Part	Cost
Linear Guide Rails	$248.90
Batteries and Charger	$719.96
Arduino Uno and Arduino Mega	$45.96
Raspberry Pis and Starter Pack	$159.81
Stepper Motor and Controllers	$177.61
Misc. Electronics	$64.11
Misc. Mechanical Parts	$20.59
3D printing	$100.00
Total	**$1,536.94**
Remaining	**$963.06**

Two major components in the final prototype of the construction marking robot were donated to the project: the robotic total station, provided by Trimble, and the Pioneer 2dx robotic platform, provided by CISCOR. The robotic total station retails at around $40,000 and the Pioneer 2dx has a base price of $3,295[1]. When calculating the total price of the system as a whole these components must be included and the price of the system constructed would be around $45,000.

Since the idea of a construction marking robot is yet to be available on the market it's difficult to compare the price of the prototype designed to a machine that does the same function. A similar product found is an automatic line marking robot used to mark soccer fields called Intelligent Marking[3]. This robot is designed to mark the lines on a soccer field with no human interaction with a ±2 cm margin. The difference between the Intelligent Marking robot and the construction marking robot that makes it more complex is the fact that the Intelligent Marking robot replicates the exact same design each run, while the construction marking robot must lay out a new design each run. The Intelligent Marking robot costs kr. 170.000, which equates to a little over $21,000, as well as a $90 monthly service subscription fee[2]. Figure 3 shows how the construction marking robot compares to the Intelligent Marking robot in price. It must be noted that while the Intelligent Marking robot is must less expensive, if the construction marking robot was produced on a mass scale with a simpler robotic platform and a different localization method it could have a more competitive price.

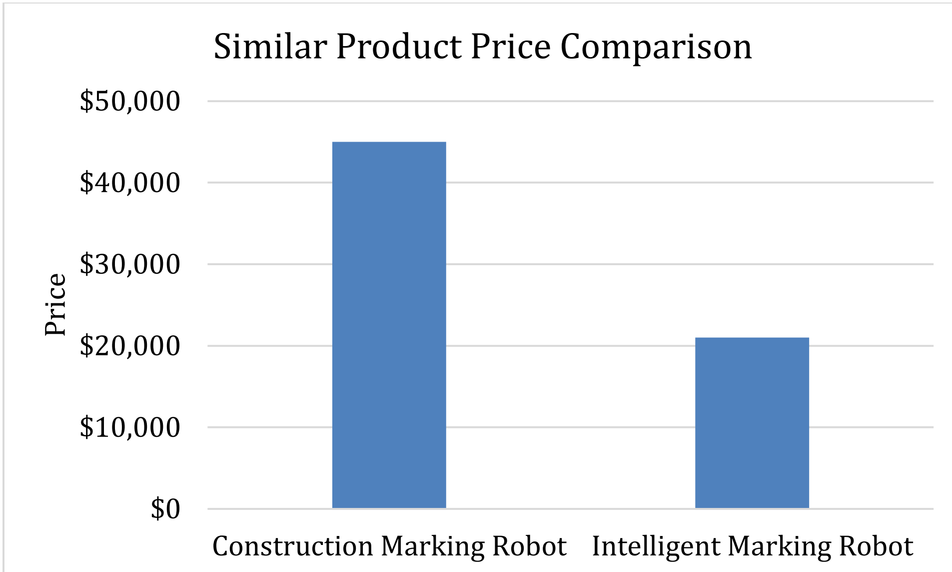

Figure 5: Price Comparison

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