Midterm I Report

Team No. 19

Construction Marking Robot

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10/30/2015

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ABSTRACT

This report encompasses the current progress of Team 19's senior design project thus far. So far the team has performed a needs assessment and determined that "*The construction industry is in need of a means of increasing efficiency and productivity as well as reducing the amount of time and error that goes into laying out floor plans manually.*" From there, the goal of "*designing a 'proof of concept' high precision marking robot that will lay out the preliminary floor plan of a construction site*" was established. Keeping these in mind, the team, using the quality, function, deployment methodology, developed a House of Quality to determine the key aspects of the design to focus on. From there each team member proposed a design and the chosen design was selected via a Pugh Decision Matrix. Currently, the team is performing further research into integrating the floor plans' CAD to the robot and further reiterating the mechanical design after discussing some potential issues with the previous one.

ACKNOWLEDGMENTS

Team 19 would like to thank Pro Steel Building Inc. for sponsoring the project and providing the team with and amazing, motivated liaison to the company.

Team 19 would also like to thank Dr. Gupta, Dr.Shih, and Dr. Collins, the academic advisors to the team, for providing them with the knowledge, criticisms, and critiques.

Team 19 would also like to thank the CISCOR group for the donation of the pioneer 2 mobile robot platform for use in our project.

1. Introduction

On a construction site, after the concrete has been poured, the structure's floor plan must be marked out in order to continue construction process. Communication issues between the contractors that are laying down their markings according to their floor plans can cause serious inconsistencies with the overall layout. Additionally, the current method of marking every floor's layout by hand is both a time consuming and inefficient process. Since all the lines of the floor plan must be marked before continuing, there is a significant delay in getting the construction job done. In order to address this issue, Team 19's sponsor, Mark Winger of PSBI, is asking for a "proof of concept" robot that will ultimately read in the complete floor plan of a given structure and mark out all of the necessary lines that the various contractors will need to have in order to place the walls, plumbing lines, electric lines, etc. of the building. This project hopes to alleviate some the work that needs to be done before the building construction takes off, while at the same time boosting efficiency by speeding up the marking process and ensuring the necessary precision of the floor plan.

2. Project Definition

1. Need Statement

The construction industry is in need of a means of increasing efficiency and productivity as well as reducing the amount of time and error that goes into laying out floor plans manually.

2. Goal Statement

Design a 'proof of concept' high precision marking robot that will lay out the preliminary floor plan of a construction site

3. Objectives

In order to fulfill the aforementioned goal, Team 19 has agreed upon the following objectives:

- Achieve basic locomotive functionality with the robotic platform being used

- Implement a means of converting the floorplan CAD data into information useable by said robot
- Design, fabricate, and implement a marking mechanism to be mounted to the robot
- Achieve communication between the robot, RTS, and the marking mechanism
- Add obstacle avoidance and error report generation functionality to the system
- Further develop the design to switch between multiple marking colors
- Test the system further with more complex layouts than used for initial testing

4. Constraints

- All marked lines must be within a half inch accuracy from the floor plan
- The total cost must not exceed $8,000
- The final design must be portable
- The robot must produce an error report
- The robot must mark 1000 square feet

5. Background and Literature Review

A major area of importance to be explored by Team 19 revolves around standard practices of the construction industry. In order to learn more about the conditions in which the robot will need to operate, the team has visited and will continue to visit a local construction site as designated by the sponsor. Additionally, the team has scheduled two informative sessions with experts in the field of robotic totaling stations.

3. Project Background

1. Pioneer 2

Figure 2- Side profile Pioneer 2-DX

The Pioneer 2-DX, the robot donated to us by the CISCOR lab, is a mobile robot that will be marking the layout plans given in CAD files. It can be seen in Figure 1. Movement will be controlled by having a program that will convert the CAD files into nodes and lines that the robot will understand. The Pioneer is a two differentially wheeled (19cm) robot with a caster for steering that will make the rotations needed to mark lines in corners. The position and orientation is coordinated based, and the Pioneer's localization will be monitored by a Robotic Total Station (RTS). Localization via the RTS is necessary because real-life factors such as surface imperfections, wheel slippage, and sensor reading errors can lead to inaccuracies in the readings from the laser range finder and imbalance in the wheels will cause the internal coordinate system to be inaccurate. Currently, the Pioneer weights around 13.5 kg with the LiDar equipped. Keeping in mind that the marking robot is to be light enough to be carried by a single person and the fact that the marking mechanism that will be included later will add weight, the team is looking to replace the heavy 12 V batteries with lithium polymer batteries, which are much lighter and more powerful for longer usage. Obstacle avoidance is another ability the Pioneer will need, and the SICK LMS 200 is equipped on top of the Pioneer for obstacle avoidance. The LMS 200 or LiDar is a non-

Figure 2 – LMS 200 LiDar

contact measurement system used for object measurement and detection and area monitoring within 15 mm accuracy. It can be seen in Figure 2. Another advantage of using the LMS 200 is that it can measure data in real-time allowing task controls from the OS. The Pioneer 2 DX has an onboard computer used to program anywhere using wireless communication.

2. Robotic Totaling Station

At the request and provision of the sponsor, the team will be using a robotic total station (RTS) in conjunction with the mobile robotic system for accurate localization. Additionally, the utilization of the RTS will require the team to design the mobile robotic system so as to include a series of prisms so the RTS can track the position and orientation of the robot. The RTS is a computer aided surveyor’s tool that uses optical sensors to measure the distance and angles of specific prisms. These prisms will be attached to the mobile robot and will communicate with the robot its position to the accuracy needed for the project. The average robotic totaling stations cost upwards of $40,000. With this price point, it is impossible for Team 19 to procure one with the allocated budget; however, the team's sponsor, Mark Winger, has contacted multiple dealers of Trimble in the Florida area and has set up two meetings within the next month. One meeting will be more informative with a local dealer and the second meeting will be a hands on training session with a second dealer.

3. Floor Plans

Normally, floor plans are simulated on computer by using CAD, computer-aided design, which create 2D or 3D graphical representations of objects. The CAD files can help visualize concepts and assist in strength and analysis to define methods for constructing. CAD can also increase the productivity of the design, perform calculations, and has great accuracy, reducing errors. Floor plans will be given to Team 19 to form of CAD files, which will be turned into a text file of coordinates.

4. Risk Assessment

There are 2 main steps to the construction marking robot that need to be analyzed for safety: the construction of the marking arm and its connection to the robot, and the use of the robot once it has been completed. For the construction of the marking arm, the process includes dealing with electrical work and the use of LiPo batteries. For the use of the robot, the actual electrical work will not be tampered with anymore, but the LiPo batteries will still have to be potentially handled. Also, the robot will be maneuvering on a construction site, which provides for many hazardous conditions.

In the construction of the robot the main risks will be dealing with the LiPo batteries, and the connection of the electrical work. One concern with the LiPo batteries is the charging. It's important to use a LiPo compatible charger using Constant Current/Constant Voltage charging or damage to the battery may occur. The other issue to consider with LiPo batteries is that they can explode or catch fire if the battery is exposed to heat or it is punctured. To combat these problems the battery needs to be placed in a fireproof container, such as a LiPo bag, and also handled with care. On the construction site the user must wear a hardhat, have closed-toed shoes, and long pants. Finally, the weight of the robot might present a small risk, so it should be transported by two people to ensure safety to the person transporting.

In the case of an accident, 911 will be called if the emergency constitutes that. Alternatively if the LiPo battery explodes or catches fire a person may go to the hospital for burns, or 911 will be called if a fire starts and is too big to extinguish safely. Also, a fire blanket or fire extinguisher will be kept nearby when conducting tests.

5. Scheduling and Task Allocation

Team 19 has a dynamic team that contains two different disciplines. Three team members are mechanical engineering majors and two computer engineering majors. This provided the team with knowledge in multiple areas of engineering and the ability to allocate tasks that require a certain background in either field to the stronger suited group of engineers.

Justin Gibbs, Kelsey Howard, and Brandon Roberts are the mechanical engineers and will be responsible for the design and production of the marking arm. Along with the core mechanical engineering courses, both Justin Gibbs and Brandon Roberts have experience in mobile robotics and mechatronics which was taken into consideration when delegating tasks. Christian Baez and

Derrick Portis are the computer engineers and will be responsible for the programming of the marking arm and the programming and function of the robot itself.

From the Gantt chart, seen in Appendix A, a complete breakdown of tasks for this project has been laid out. The Gantt chart was separated into 3 main sections: conceptual design, product architecture, and programming. The conceptual design portion has been completed, although an iteration of the House of Quality and Pugh Matrix is still necessary, the product architecture is currently being completed, and research is being done for the programming portion. The conceptual design selection was completed mostly by the mechanical engineers, in terms of designing the marking arm, and the entire team was responsible for the initial tasks which included tasks such as finalizing a problem statement, and gathering information. In the product architecture the mechanical engineers will also play a large part when finalizing the design, creating CAD parts, and doing analysis. Finally, the computer engineers were tasked completely with the programming section.

6. Concept Generations and Results

1. Methodology

In order for the robot to accomplish the task of reading in a CAD file of a floor plan and then marking it out in full scale on concrete, a top level program will need to be implemented that will communicate directly to the robot. The current plan is to take existing code that will read in a CAD file and return a text file of coordinates, or a matrix of nodes and its connected neighbors. From there another program will be written that will read in this text file and call the robot's movement functions in order to get to the coordinates on the CAD file. This program will also control when the arm of the robot is up or down for marking purposes. In addition, the robot will be communicating with the robotic total station in order to make fine adjustments to ensure that all of the marks made maintain a half inch precision when compared to the floor plan.

2. Design Process

For the Construction Marking Robot, Team 19 will implement a strategy focused around the preliminary design of the system similar to the one mentioned in *Engineering Design* by George Dieter. The team will be using a product development process known as Quality Function Deployment (QFD), which is a graphical, multistep process that creates relationships between key parameters throughout the entire design process. This tool will help focus the team's attention to satisfying the customer's needs. One of the beginning steps of this process is constructing a House of Quality (HOQ), which is a design tool in the form of a relationship matrix which compares the customer's needs to the engineering characteristics set by the design team. An example of a HOQ for the Construction Marking Robot can be seen in Appendix A. Once the final design has been selected, the team will move into the embodiment phase of the design where more specific figures and values will be chosen. QFD is a very iterative and involved process which will make for a better final design.

Team 19 used the HOQ to determine what the most important characteristics of the design were according to the customer. The team first sent a survey to the sponsor asking to rank certain design aspects for a better scope of the final outcome. This survey can be found in the Appendix A. This HOQ determined that the team needs to focus on the battery life and the weight of the final design. Although these may not be the most important, it is something to focus on throughout the design process.

After the HOQ was used to determine key parameters to focus on throughout the design, there was an individual brainstorming session in which each member took the key parameters and designed a concept for the marking arm. From the whole of the concepts, the top three designs were chosen and can be seen in Figures 3, 4, and 5. These designs were then discussed as a group to find the best and worst aspects of each. From a comparison to target values from the House of Quality, the team then took the best components of the initial designs and created a fourth design, seen in Figure 6. These four designs were then compared in a Pugh Decision Matrix, which can be found in Appendix A, and a final design was chosen. From the Pugh Matrix it was decided that Design 4 was the best design in terms of meeting target goals, fulfilling project requirements, as well as taking into account the most important parameters.

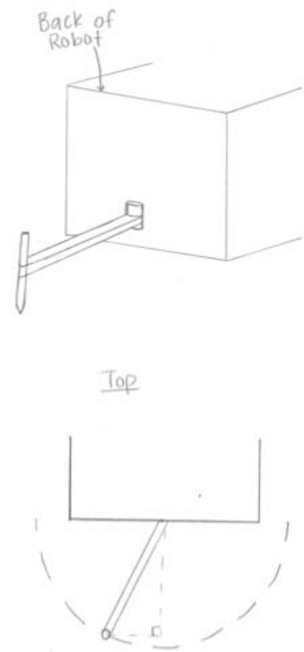


Figure 3 – Design Concept 1

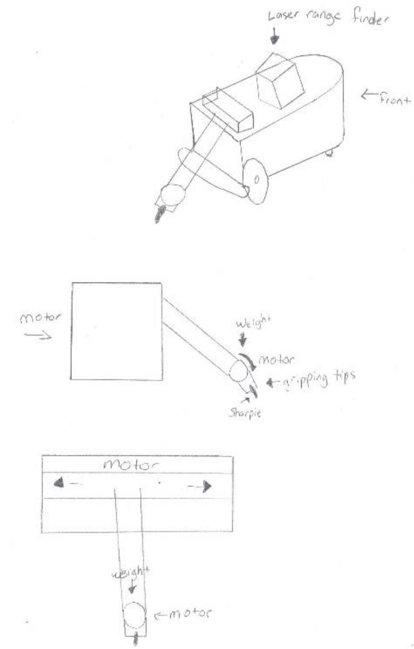


Figure 4 – Design Concept 2

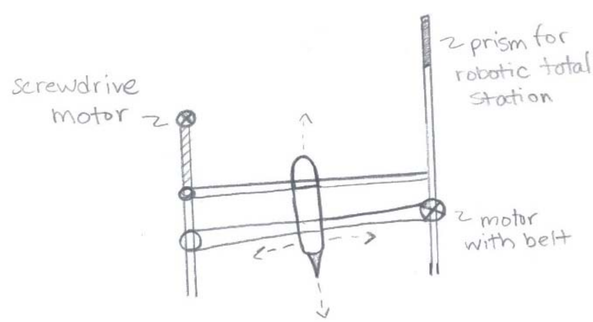


Figure 5 – Design Concept 3

3. Results

1. Selected Design

Figure 6 - The initially selected marking mechanism design concept

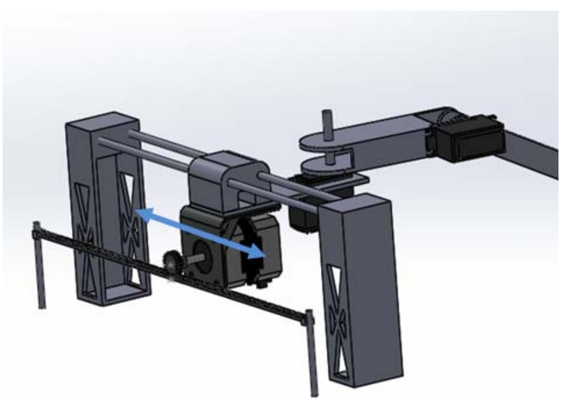


Figure 7 - Translational motion from the motor driven rack and pinion

The design selected from the proposed designs was one which encompassed what the team believed to be the best attributes from the earlier proposed designs. The primary goal of this design was to remain as simple as possible while still allowing the accuracy desired by the customer. As can be seen in Figure 6 , the design consists of two servo motors attached to two lever arms, a stepper motor which drives a rack and pinion, and necessary supports and guide rails. The stepper motor-rack and pinion set is meant to allow translational motion along the horizontal plane of the robot, between the wheels, as depicted in Figure 7. As seen in Figure 8, the servo motor-lever arm pairs are meant to allow for rotational motion; the first for raising and lowering the marking arm, and the other for additional reach along the horizontal plane by arching the marking arm outside the track width of the robot. As desired, this design would be fairly simple with respect to its mechanical design and requirements for actuation; however, upon further discussion and review, the team has reached the conclusion that this design may, in fact, be too simple to the point of causing

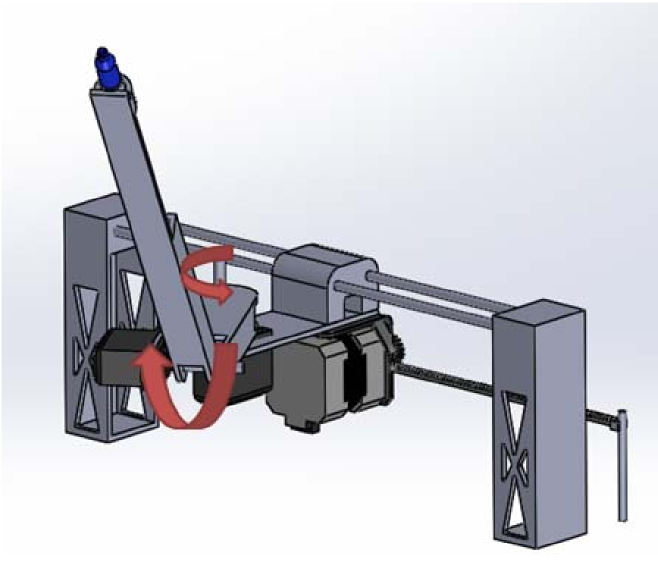


Figure 8 - Angular motion from both servo motors

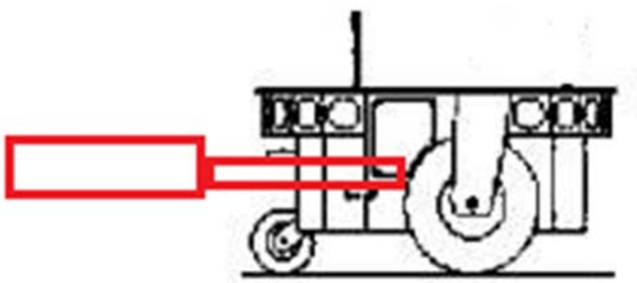


Figure 9 - Proposed method of mounting the new marking mechanism

issues further along the design and implementation process.

2. Design Issues and Future Improvements

After further discussion amongst the group and receiving feedback from an advisor, it was agreed upon that the marking mechanism design needed to be revised for a few key reasons. First of all, the current arrangement did not account for being able to use multiple marking colors. While the team did want to originally focus on one color to first achieve functionality of the marking mechanism before moving into such improvements, it was agreed upon that the current design accounting for only one marker was too simplistic. In other words, while only designing for one marker would potentially be simpler; it could cause potential issues further along the project once the team tries to integrate a mechanism for switching colors. Additionally, the current marking mechanism is flawed for applying an appropriate force to the marker when marking. With the current design of basically dragging the marker, the resulting marks would most likely either be too light and not straight or too much force could be applied in a vertical configuration which would wear down and potentially break the tip of the marker.

Keeping the aforementioned issues in mind as well as reassessing the design's future usefulness, the team has decided to focus on adjusting the design to function in a similar manner to a 3-D printer. While this redesign is still being developed, the basic idea is to mount two lever arms to the sides of the Pioneer 2-DX, as seen in Figure 9, which will support a square frame which contains motor driven rods, one for moving amongst the mechanism's y-axis, and the other for the x-axis, seen in Figure 10. At the intersection of these two rods will be the mechanism for holding the marker and, eventually, for selecting the marker, the latter of which will most likely be done with some type of spring-based compression so as to apply an appropriate amount of pressure onto the marker for varying surface levels, as is common with the concrete pours seen on construction sites. Once this design has been reworked, the team will focus on first building a functioning purely mechanical prototype, then move into integration with the rest of the system for autonomy.

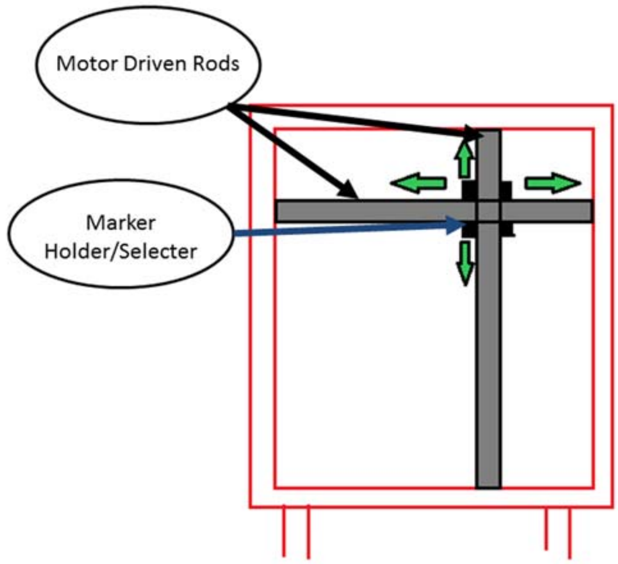


Figure 10 - Concept for new marking mechanism

3. Hurdles to Overcome

There are some challenges that will need to be overcome before this project can be completed. The robot, floor plan, and the total station all consist of a different coordinate system. This means that an algorithm will need to be implemented that will line up the coordinate systems in order to accurately convert the floorplan to full scale markings. The robot currently measures distances in the Metric system whereas the floor plan follows the English system. As a result, to maintain consistency, conversion of one system to the other will be necessary; however, this will lead to a loss in precision. In addition, the team has yet to receive the API of the robotic total station, without this information the robot will not be able to communicate to the robotic total station and make the necessary adjustments it needs when marking to maintain the half inch precision when compared to the original floor plan. It is also understood that the construction site may not be cleared of objects, because of this a program will need to be implemented that receives data from the Lidar of where the object may be and then develop an alternate route for the robot to go around the object to continue marking lines. This program will also need to store the location of unfinished lines due to obstacles.

7. Conclusion

This project will help introduce advancements of technology in the construction industry. In designing this "proof of concept" construction marking robot, the team's goal is to show that new technology will make any construction job more efficient and can be relied upon. By being able to handle the marking of the entire floor plan while maintain its precision, the construction survey robot will increase productivity and cut down on the time it takes to finish a construction job. In regards to finalizing the process of the construction marking robot, it meets the customer's need of reading in a CAD file of a building's floor plan and then turns that file into coordinates in order to know where to mark. By communicating with the robotic total station, the robot will be able to maintain the precision within a half inch of the original floor plan as it marks out the lines. Additionally, the team is currently working on reiterating the selected design due to issues related to the marker in terms of being too simplistic to account for multiple colors of markers as well as not being able to apply proper pressure on the marker. As such, the team is currently referencing 3D printers as a potential source of inspiration for the revamped design and currently exploring a means of using springs to keep the marker properly pressed down to ground at an adequate force.

8. References

[1] "Project Lion - A DPR/Trimble Automated Layout Robot." *YouTube*. YouTube, 25 Apr. 2013. Web. 25 Sept. 2015.

[2] Prouty, Joseph M. Robotic Construction Site Marking Apparatus. Joseph M. Prouty, assignee. Patent US 20130310971 A1. 21 Nov. 2013. Print.

[3] "Construction Industry- Robotic Layout." *Totalmark Technologies*. N.p., n.d. Web. 25 Sept. 2015.

[4] "Specifications & Controls." *ActivMedia Robotics Pioneer 2/PeopleBot Operations Manual V10*. N.p.: n.p., July 2002. 10-18. Print.

9. Appendix A

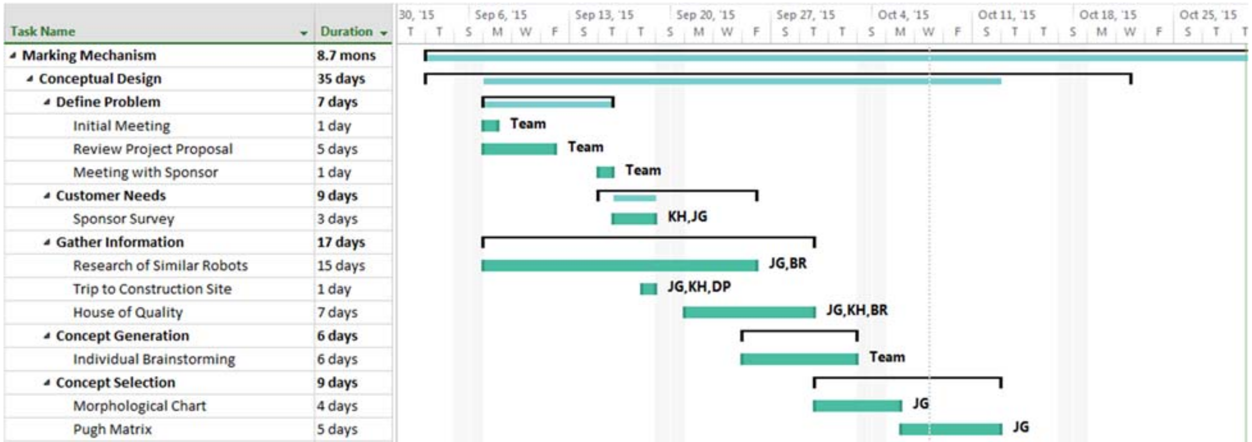


Figure 11 – Gantt Chart: Conceptual Design

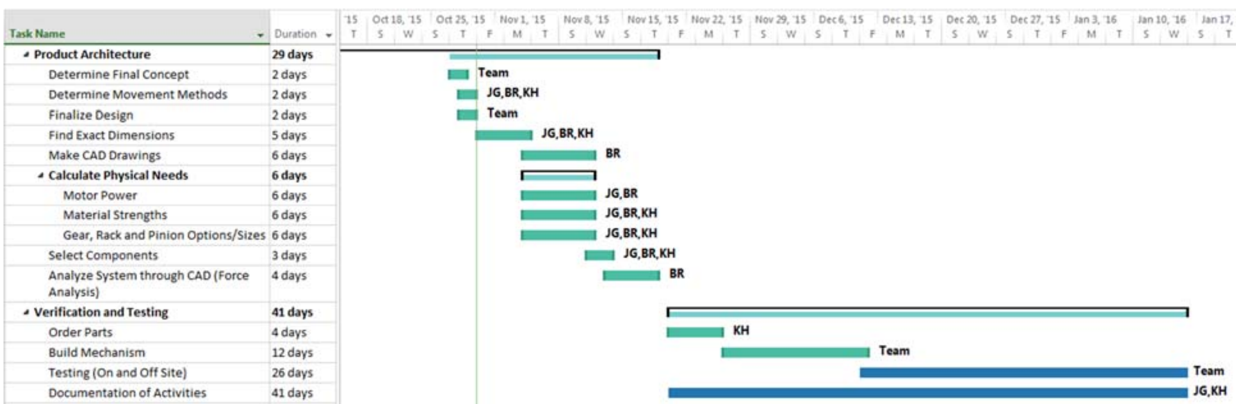


Figure 12 – Gantt Chart: Product Architecture

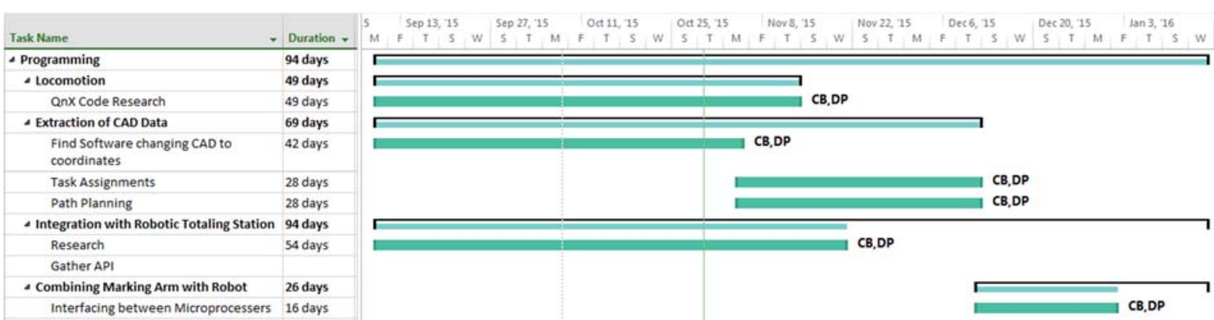
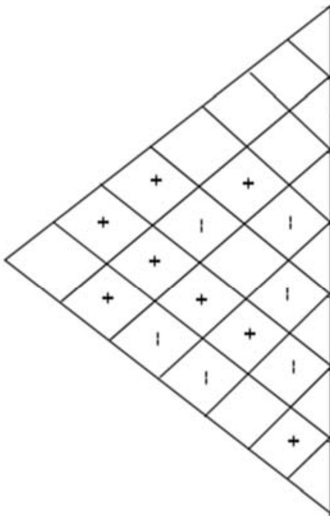


Figure 13 – Gantt Chart: Programming



Engineering Characteristics →		Rate of Coverage	Cost	Weight of Device	Battery life	Precision	Total Area Coverage	# of Colors	Selling Points	Competitor A	Competitor B	Target Values
Customer requirements	Importance to Customer											
Functionality	5	10	5	2	8	10	10	10	275	4	4	5
Easy to Operate	3		5			2		2	27	4	4	4
Light Weight	4	7	8	10	10		7	4	184	4	5	5
Safety	5			7		5			60	3	5	5
Portability	4	3	5	10				2	80	4	3	4
Price	1	3	10	7	8	5	2	5	40	3	4	4
Durability	4		5	3					32	3	3	4
Aesthetically pleasing	1							5	5	3	4	4
Serviceablity	3		3		7			5	45	3	4	4
Other specific needs ↓	Importance Weighting →	93	131	144	109	86	80	105				
	Competitor Comparison											
	Direction of Improvement	+	o	-	+	+	+	o				
	Laybot	?	?	75 lb	???	???	?	1				
	Markbot	?	?	?	???	???	?	1				
Robotic totaling station ; error report	Target Values	10SQFT /min	<$8000	<100lb	>4hr	???	100 FT^2	>1				

Figure 14 – House of Quality

Requirements	**Functional Parameters**	**Concepts Solution**			
Functionality	Marking Reach	Inside of Robots Tires		Outside of Robots Tires	
	Marking Mechanism	Belt Driven	Manipulator Arm		Rack & Pinion
Ease of Operation	Degrees of Freedom	1	2	3	7
	# of Motors	1	2	3	4
Lightweight	Material Selection	Aluminum	Steel		ABS Plastic

Table 1- Morphological Chart

<u>Importance of Customer Needs</u>

Importance ranking (1-10, with 10 being with the utmost importance)

Serviceability	5_____
All weather	3_____
Safety	10_____Can you clarify what you mean by safety? Whose safety? Operates safely? Safety is a big deal in construction.
Error report	10____
Tolerances on error report	10____
Durability	7_____
How many SQFT	100___
Cost of manufacturing	1_____
Time of operation	10_____ 100 sq.ft. in 10 minutes?
User friendly	5_____
Level of autonomy	8_____
Use of robotic totaling station	10____
Marking arm	1_____
Transportability	8_____
Ability for more colors	5_______ What do you mean? Like using an inkjet printhead over vs pen?
Accuracy	10_____ ½”
Line continuity	7_____
Different terrains	3_____
Other uses for robot	4_____
Sharpie for marking	2_____

10. Biography

Justin Gibbs – Justin is a Mechanical Engineering senior currently studying at Florida State University. Justin looks to expand his knowledge base and continue his education in hopes of receiving a Ph.D. and eventually being a professor.

Christian Baez - Christian is a Computer Engineering student at Florida State University. Christian seeks to start his career after graduation, becoming an asset for his company.

Derrick Portis - Derrick is a senior at Florida A&M majoring in Computer Engineering. Derrick looks to start working as a software engineer after graduation.

Kelsey Howard - Kelsey is a Mechanical Engineering senior at the FAMU-FSU College of Engineering. Upon graduation Kelsey looks to start working in industry with a focus in thermal fluids and thermal fluid design.

Brandon Roberts - Brandon is a senior in Mechanical Engineering at the FAMU-FSU College of Engineering currently seeking his Bachelor's of Science with plans to move to seeking his Master's degree through the university's BS/MS program, then moving on to industry.