Final Report

Team No. 19

Construction Marking Robot

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Abstract

Due to the inefficient and error prone way of currently laying out the floor plans of a construction site, Mark Winger of PSBI has sponsored a team to create a robot that will plot the floor plans of a construction project full scale on the concrete slab. The construction marking robot is a proof of concept, high precision marking robot that will lay out the preliminary floor plans of a construction site, increasing the efficiency and productivity of the layout process. The final product must be able to make marks within ½” accuracy, be easily portable, able to mark on concrete, able to mark across 100 sq. ft. within 10 minutes, and be able to navigate autonomously. The robotic platform is the Pioneer 2-DX, which is a differentially steered, mobile research robot that holds a SICK LMS 200 LIDAR system. The LIDAR will be used for obstacle detection. For increased precision the robot will communicate with a robotic total station, which aids in localization. For the marking mechanism, a gantry system will be attached to the rear of the robot. Finally, a raspberry pi 2 microprocessor will be used to aid in communication between the robotic total station and the Pioneer 2-DX, as well as controlling the movements of the gantry system.

1. Introduction

Mark Winger of PSBI introduced the project of a construction marking robot as a way to lead technology into the construction industry. He believes that introduction of robotics in the construction industry will increase both efficiency and productivity in the work force. Currently there is an absence of robotics in the industry because of a lack of trust in automated processes. The construction industry is rooted in the work of tradesmen who learned and excelled at particular aspects of the construction process and did all work manually. Due to this, there is a greater trust in individual manual labor instead of robotics.

With this need in mind, Mr. Winger saw that the process of marking floor plans on the concrete slab of a construction site before installation of interior components was both slow and inaccurate because it is done manually. He proposes a robot that will take the 2D CAD floor plans and plot them on the concrete slab at full scale.

With this information the team found that the current need in the construction industry is 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. The goal to meet this need is to implement a proof of concept high precision marking robot that will lay out the preliminary floor plan of a construction site to increase efficiency and productivity in the layout process.

2. Background and Literature Review

The idea of a construction marking robot is a fairly recent idea in the construction industry. Currently there is research being done with the idea by companies such as Trimble and DPR, who are combining their specialties in GPS positioning products and construction to create an automated layout robot, or Laybot as they have termed it. This Laybot idea is similar to the group's construction marking robot in that it hopes to be able to mark multiple layouts on the ground, use downloaded 2D CAD files to input the layouts into the robot, and have communication with a robotic totaling station to ensure precise positioning[1].

Aside from the Laybot idea, there is also a patent for a construction marking robot by Joseph M. Prouty with Totalmark Technologies[2]. While designed to perform the same function as both Team 19's design and the Laybot, the robot by Totalmark Technologies "is controlled via an included tablet pc which is accessible via the internet from anywhere in the world, so long as the job site has Wi-Fi access."[3] It also is linked with a robotic totaling station to track position, and is able to function in complete darkness.

The differences between Team 19's design and the others are the plan of a different marking mechanism and different sensors on the robot. With the resources provided to the group, and the materials available, the final design for the construction robot is guaranteed to be different than the products currently being researched and produced by other companies.

2.1 Construction Industry

2.1.1 Floor Plans

Floor plans in the construction industry are the means of communicating how the structure is to be built to each person on the job site. These plans, which are simply 2D CAD drawings designed by an architect, show a scale diagram, as viewed from above, of each component in the structure. Different subsystems of the building, such as interior walls, sprinkler systems, plumbing, HVAC systems, etc. are shown at different levels on the plans for each respective subcontractor. The essential components of these CAD drawings are what the construction marking robot will be transferring onto the concrete slab of the building before internal construction begins. For example, Figure 1[4] shows an example of a 2D CAD drawing for the sprinkler system in a residential building. The construction marking robot would be responsible for marking both the location of the sprinkler heads, as well as the piping leading to each.

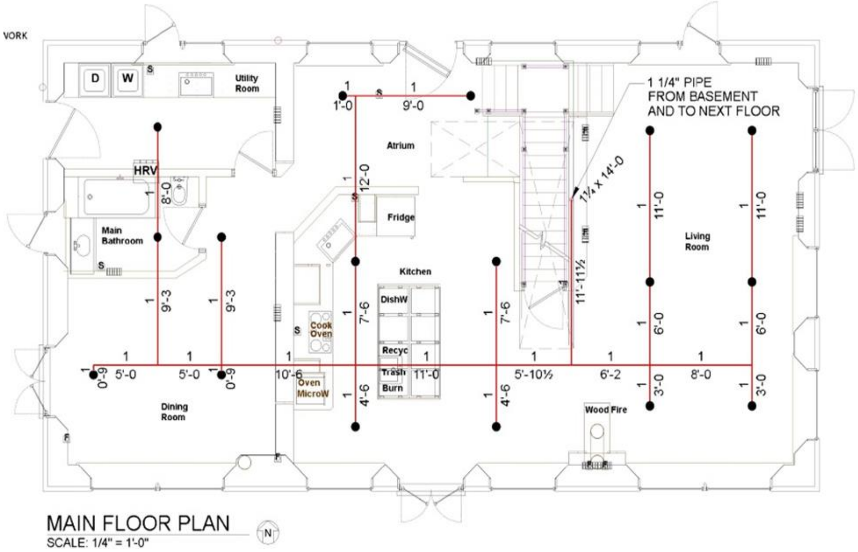


Figure 1 – Example Floor Plan

2.1.2 Layout of Floor Plans

After the concrete slab has been poured, each of the interior components of the building must be marked on the slab to show where instillation will occur. These components include locations of interior walls, electrical wall outlets, sprinkler systems, HVAC systems, etc. The current method of laying out floor plans on a construction site is manually. Points from the floor plans are marked on the ground after being measured from a known location on the plans with a ruler, and subsequently on the concrete slab using a measuring tape. If necessary, connections between these points are placed by using a chalk line, such as when laying out the interior walls of the building, as seen in Figure 2[5], which shows an example of an interior wall marked on the slab. For other subsystems of

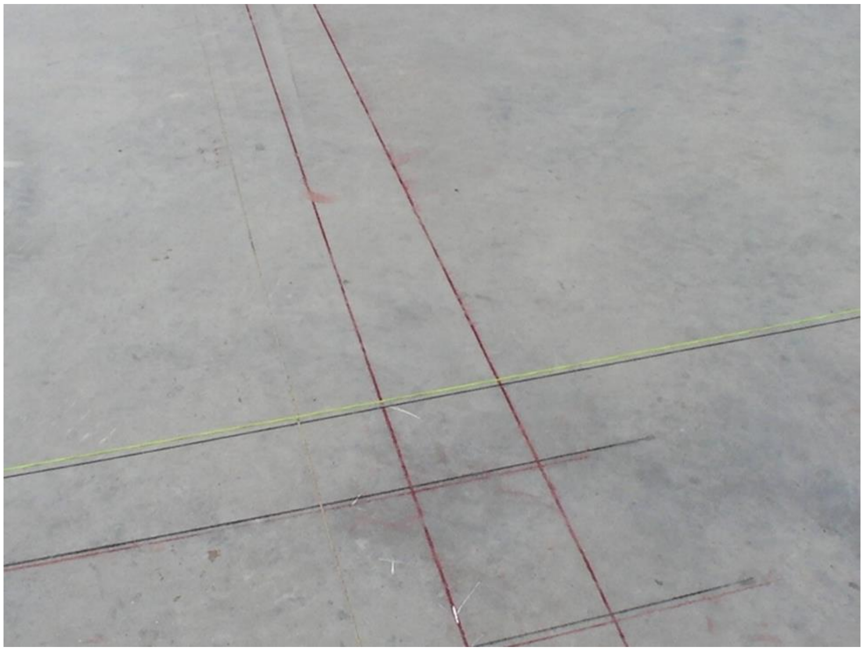


Figure 2 – Example Construction Marks

the structure, such as sprinkler heads, electrical wall outlets, and light switches, a simple mark might suffice. Each subcontractor is responsible for marking their own components on the concrete slab, as well as installation of their parts.

There are various ways in which issues can arise when marking the slab manually. For one, there is always error when work is done by humans. This human error can come from using a ruler and tape measure to measure the floor plans and the concrete slab, as well as taking those measurements and translating them to marks on the slab. Human error can also have an effect by taking measurements from different points of origin. This can quickly lead to error propagation throughout the building. Since the majority of the parts come pre-built, such as the interior walls and HVAC system, any small error is multiplied through the building because corrections to the structures are not easily made. For example, if a wall is measured and marked incorrectly by ¼", and the next wall is measured from that wall and is also marked incorrectly by ¼", it is easy to see how by the end of the building there has been a transmission of error and there is much greater deviation from what is displayed on the floor plans. Finally, with multiple subcontractors coming in to mark their respective components on the slab, there may be discrepancies between them. While the floor plans clearly show where each subsystem is meant to be placed, in actuality many subcontractors and workers rely on their expertise to decide where to place their parts. This means that parts often end up in relatively close, but not exactly where they appear on the floor plans and can cause disagreements when each subcontractor is attempting to do their work separate from the floor plans.

The purpose of the construction marking robot is to alleviate these problems. Since the robot will be working in conjunction with the robotic total station, it will know its exact location in real time. This eliminates the human error of ensuring the marks are in the right location, and also the error propagation because it is able to constantly be checking to ensure it is in the correct location. Finally, since the floor plans will be directly shown on the concrete slab there will be less discrepancies between workers in various subsystems because the exact locations of their respective components are clearly displayed.

3. Methodology

Objectives for the project were determined based on needs and goals determined by the team in the beginning stages of the project. These objectives are what the team hopes to accomplish by the end of the time allowed. The objectives for the completion of the construction marking robot are to:

- Add functionality to the robot to receive a CAD file of a floor plan and convert it into useable coordinates
- Design, fabricate, and implement a marking mechanism
- Make the robot able to navigate autonomously, avoid obstacles, and generate an error report

Design requirements for the construction marking robot were determined by the sponsor for the group. These requirements are what the sponsor would like the robot to be able to accomplish in its final design. While these requirements are going to be the ultimate goal for the prototype produced by the group, it is realized that the product developed by the team is a prototype and may not achieve all of the design requirements. The design requirements of the construction marking robot are that the final product must be able to:

- Make marks within 1/2" accuracy
- Be easily portable
- Mark on concrete
- Mark across 100 sq. ft. within 10 minutes
- Navigate autonomously

Figure 3 shows the general block diagram of how the team plans on fulfilling these objectives and design requirements. Initially a program must be implemented to convert the floor plans into useable coordinates. These coordinates must then be sent to the robot. Finally, the robot must be able to move in conjunction with localization, the marking arm, and obstacle avoidance.

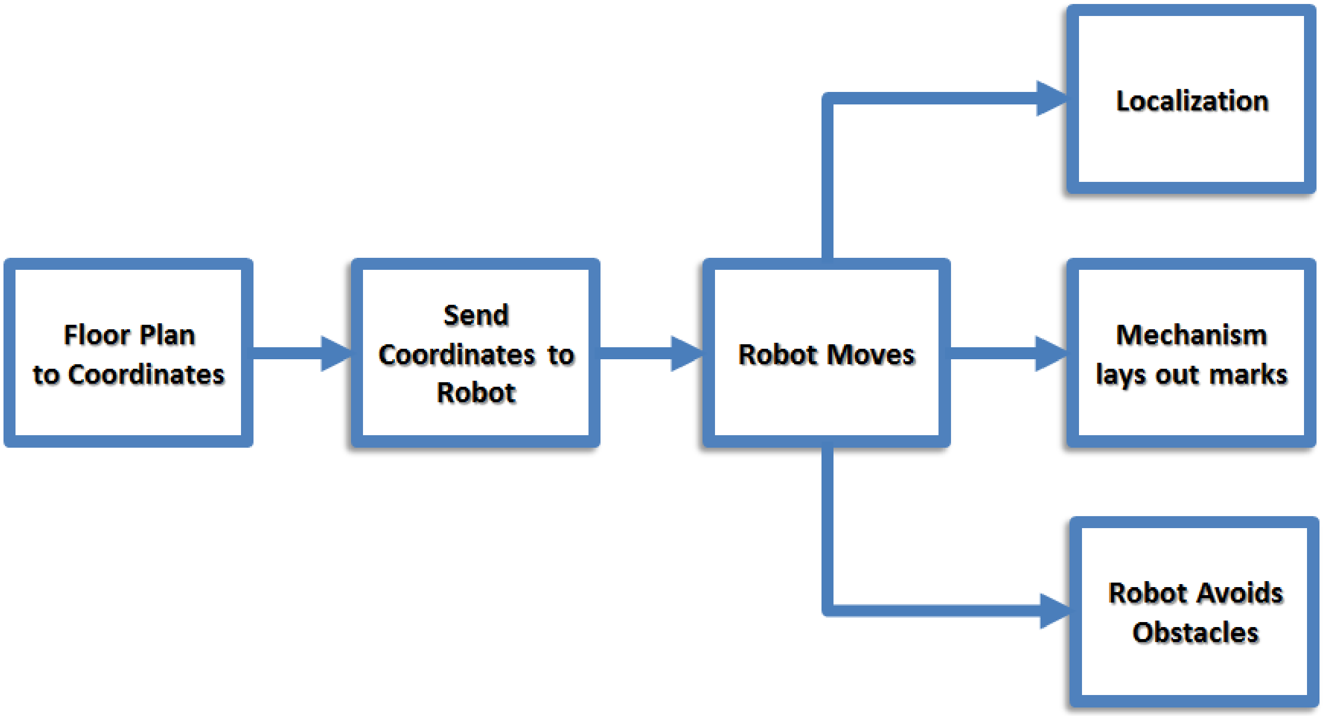


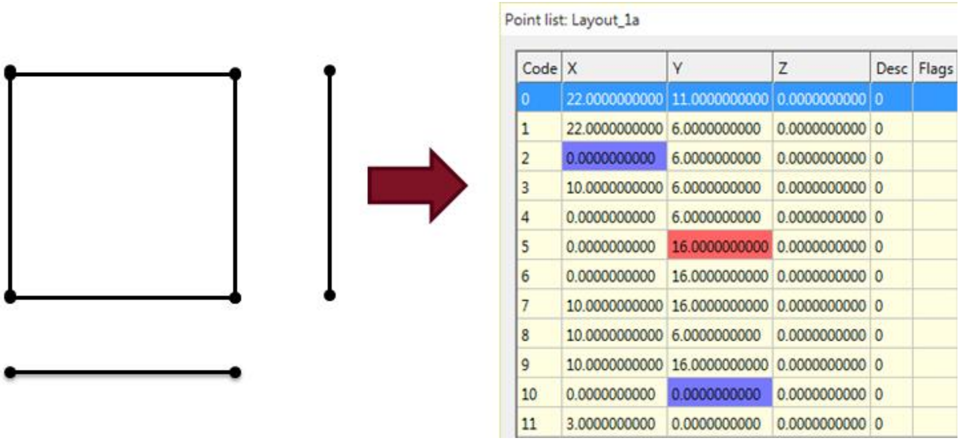
Figure 3 – General Block Diagram

3.1 Software

The floor plan is given as a CAD file. For the project, Team 19 will convert the CAD file to a text file of coordinates so that the information on the floor plan will be easy to access. The coordinates will be points along the layout lines given in the floor plan, which will allow the robot to move and mark out the layout lines by moving to the points and marking when necessary. Team 19 is using software created by Ransen Labs called *Pointor* combined with a density propagation program created by the team in order to accomplish this goal.

3.1.1 Pointor

The *Pointor* software reads in a CAD file, analyzes the lines that make up the floor plan, and displays the endpoints of those lines. The program can also analyze curves, but we will not be testing with this feature for the proof of concept. In the case of corners, or even a square, the software will simply repeat a coordinate since it lists each line as pairs of endpoints, which is beneficial to the team because the team will know that while the robot is moving from the start point of one pair to the endpoint, the robot will be marking. After generating the point list of coordinates, the program allows for exporting the point list as a text file. In figure 4, we see how the *Pointor* software takes a simple CAD file containing a single square and two lines and converts it to coordinate pairs for each line.



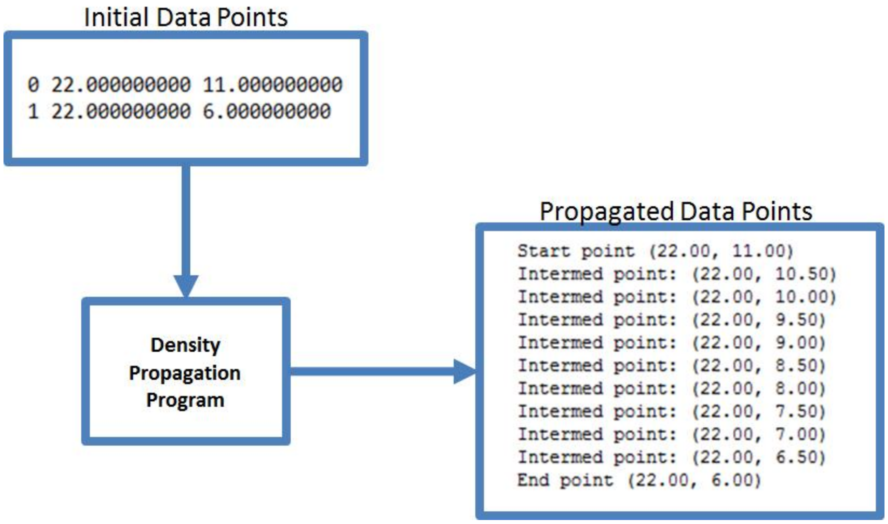
Point list: Layout_1a

Code	X	Y	Z	Desc	Flags
0	22.0000000000	11.0000000000	0.0000000000	0	
1	22.0000000000	6.0000000000	0.0000000000	0	
2	0.0000000000	6.0000000000	0.0000000000	0	
3	10.0000000000	6.0000000000	0.0000000000	0	
4	0.0000000000	6.0000000000	0.0000000000	0	
5	0.0000000000	16.0000000000	0.0000000000	0	
6	0.0000000000	16.0000000000	0.0000000000	0	
7	10.0000000000	16.0000000000	0.0000000000	0	
8	10.0000000000	6.0000000000	0.0000000000	0	
9	10.0000000000	16.0000000000	0.0000000000	0	
10	0.0000000000	0.0000000000	0.0000000000	0	
11	3.0000000000	0.0000000000	0.0000000000	0	

Figure 4 – Floor plans to coordinate file

3.1.2 Density Propagation

The team created a density propagation program that could read in the coordinate pairs and generate intermediate coordinate points that are a half inch apart. By adding these intermediate points there will be less line loss when moving around an obstacle because instead of leaving the rest of the line unfinished, the robot will be able to get back onto the closest intermediate point after the obstacle and continue the line. Figure 5 is a block diagram illustrating how the density



```
0 22.000000000 11.000000000
1 22.000000000 6.000000000
```

```
Start point (22.00, 11.00)
Intermed point: (22.00, 10.50)
Intermed point: (22.00, 10.00)
Intermed point: (22.00, 9.50)
Intermed point: (22.00, 9.00)
Intermed point: (22.00, 8.50)
Intermed point: (22.00, 8.00)
Intermed point: (22.00, 7.50)
Intermed point: (22.00, 7.00)
Intermed point: (22.00, 6.50)
End point (22.00, 6.00)
```

propagation program reads in a coordinate pair and return a list of intermediate points.

Figure 5 - Density Propagation Diagram

3.2 Hardware

3.2.1 Raspberry Pi 2

Figure 6 - Raspberry Pi 2

This credit card sized microprocessor is a 900 MHz quad-core ARM Cortex-A7 CPU with 1 GB RAM memory. It can be visualized in Figure 6. A microprocessor is a computer processor that involves most functionalities of a conventional computer's CPU on a single integrated circuit. The microprocessor is also programmable to fit any need for the device. The Raspberry Pi 2 will handle connecting the different components with our system. It has 40 general purpose input-output pins to handle all physical connection. It will also hold the software to run the Density Propagation program and the Pointor software. We chose this microprocessor over others because the Raspberry Pi 2 has the widest OS support compared to other running both Linux and Windows 10 operating systems and the price was reasonable for the functionality. The downside to our selection is the number of bytes processed per second. Another important aspect that swayed our decision was the amount of free memory after being booted to a desktop.

3.2.2 Mobile Robot Platform

Figure 7 - Pioneer 2DX

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 7. 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). 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-contact measurement system used for object measurement and detection and area monitoring within 15 mm accuracy. It can be seen in Figure 8. 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.

3.2.3 Obstacle Avoidance

A LIDAR system would be most efficient for obstacle avoidance when compared to sonar sensors or IR sensors. The LIDAR in this project is to be used for obstacle avoidance. The specific lidar being used is a SICK Laser Measurement System (LMS) 200 and can be viewed in Figure 8. It is a non-contact measurement system used to measure the distance of objects within a 180 degree field in front of the robot.

The obstacles that the robot may encounter during operation can be anything from rebar, PVC pipes, holes, curbs, to people, or trash that may be present on the construction site. A picture of a typical construction site at the time the robot will be marking can be seen in

Figure 9 – Typical Construction Site

Figure 9. The robot needs to avoid these obstacles for self-preservation, the safety of other workers, and so that the floor plans get plotted correctly.

The plan for obstacle avoidance is simple. When the robot detects that an obstacle is within the radius of influence, or the distance which is considered dangerous, the robot will veer from the desired path and return to the desired path only when the path is free of obstacles. Figure 10 illustrates this concept. There will be certain applications of path planning and replanning that will be looked into further by the team in the future.

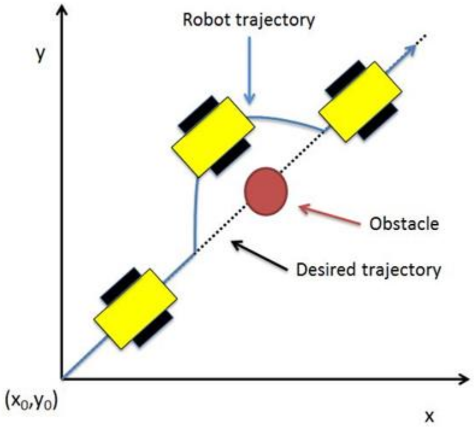


Figure 10 – Obstacle Avoidance Strategy

The Sick LMS 200 has 3 different settings that it can operate in. The 3 different modes can be seen in Table 1 and are differentiated by the number of measurements made in one pass and the field of vision. The team has chosen the setting in which the LMS 200 has a full or 180 degree field of vision and the most number of measurements for that field of vision. It is labeled as having an angular resolution of 0.5 degrees. This was done to ensure that the LIDAR has the most amounts of data possible for the full range of vision. This was done because some of the obstacles encountered on the construction site are small or thin and the robot needs to be able to avoid them flawlessly.

Angular resolution	**0.25°**	**0.5°**	**1.0°**
Max Scanning angle	100°	180°	180°
Max # of measure values	401	361	181

Table 1 - LMS 200 Modes

3.2.4 Robotic Total Station

In order for the robot to plot the floor plans in the correct positions the robot will need to implement localization or know its exact location in the construction site. Some sensors that can be used for localization include GPS, visual sensors, and wheel encoders. These sensors do not have enough accuracy for our robot. The sponsor had an idea of implementing an existing technology in the construction industry into the project for localization.

Figure 12 – Robotic Total Station

Figure 11 – Reflective Prism

Localization will be done with the use of a robotic total station. A robotic total station similar to the one being used by the team can be seen in Figure 11. It will be provided by Trimble and will include a reflective prism for tracking, a tablet for communication, a software suite along with an API for integration of the raspberry pi and robotic total station.

A robotic total station is a measurement system similar to the LIDAR system previously noted. The RTS uses optical sensors to measure the exact position of a reflective prism which can be seen in Figure 12. The RTS makes its measurements by knowing the angles at which it is oriented and the slope distance to the target.

The RTS uses triangulation to specify its location in the global frame. This is done by knowing 2 points of interest and their global coordinates to measure where it is in comparison to the floor plan. The RTS will be used to be sure that the marks the robot makes are in the correct position in relation to this floor plan as well. 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.

The team was provided a formal class dealing with Trimble's technologies including the robotic total station and 3D point cloud analysis. It was administered by a sales representative and ex-employee of Trimble, Rob Miller. Rob has recently communicated with Trimble about our team and the project. Trimble is currently in the process of donating all of the technology the team will need to implement this system into our design. This is great because the typical package cost is in excess of $40,000 which is well out of the team's budget. Rob also plans to meet with the team a few times next semester for guidance with the project since he did work with the Project Lion explained in the introduction.

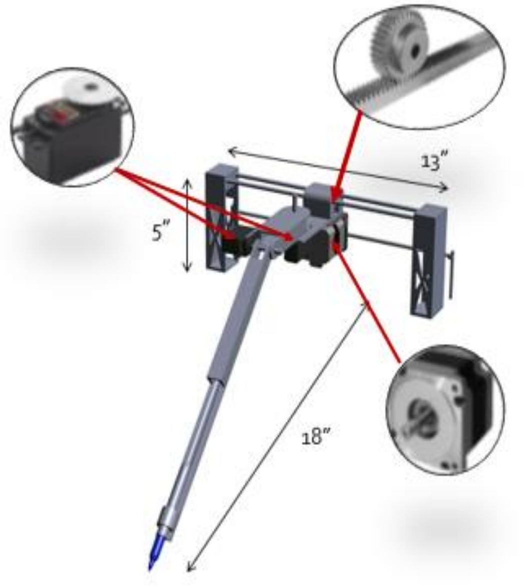


Figure 13 – Original Marking Mechanism

3.2.5 Mechanical Design

3.2.5.1 Previous Design – Lever Arm Linkage

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 13, the design consisted of two servo motors attached to two lever arms, a stepper motor which drove a rack and pinion, and necessary supports and guide rails. The stepper motor-rack and pinion set was meant to allow translational motion along the horizontal plane of the robot, between the wheels, as depicted in Figure 14. As seen in Figure 15, the servo motor-lever arm pairs were 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 reached

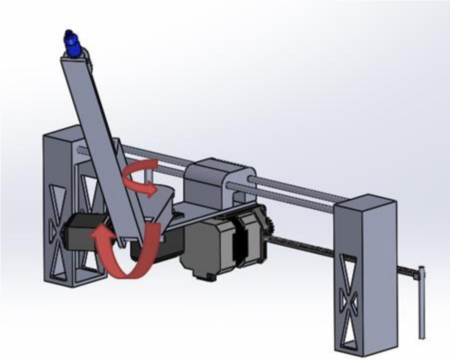


Figure 14 – Translational Motion Visualization

Figure 15 – Rotational Motion Vizualization

the conclusion that this design may, in fact, be too simple to the point of causing issues further along the design and implementation process.

3.2.5.2 Previous Design Issues and New Proposed Method

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.

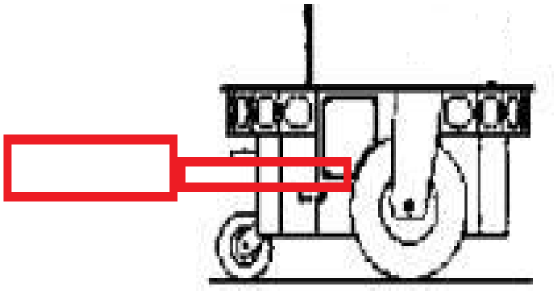


Figure 17 – Mounting Method

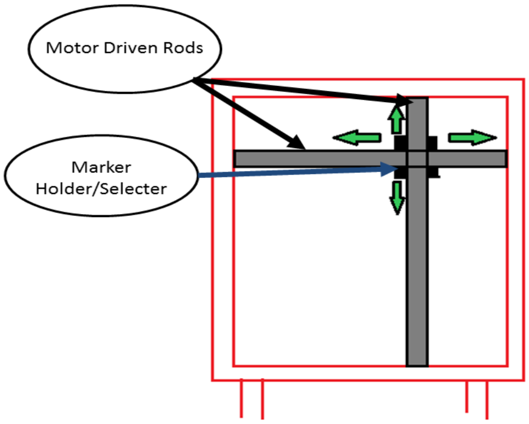
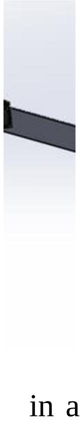


Figure 16 – Gantry Schematic



Keeping the aforementioned issues in mind as well as reassessing the design’s future usefulness, the team decided to focus on adjusting the design to function in a similar manner to a 3-D printer. The basic idea was to mount two lever arms to the sides of the Pioneer 2-DX, as seen in Figure 16, 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 17. 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.

3.2.5.3 New Design - Gantry

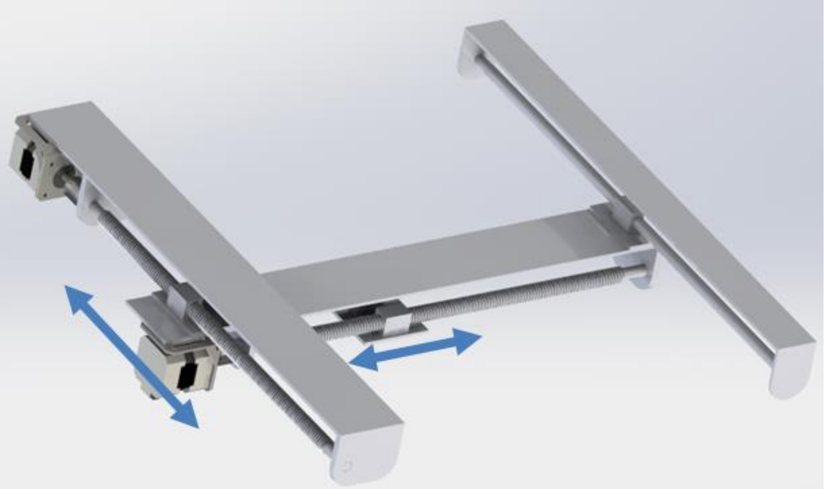


Figure 19 – New Marking Mechanism Design

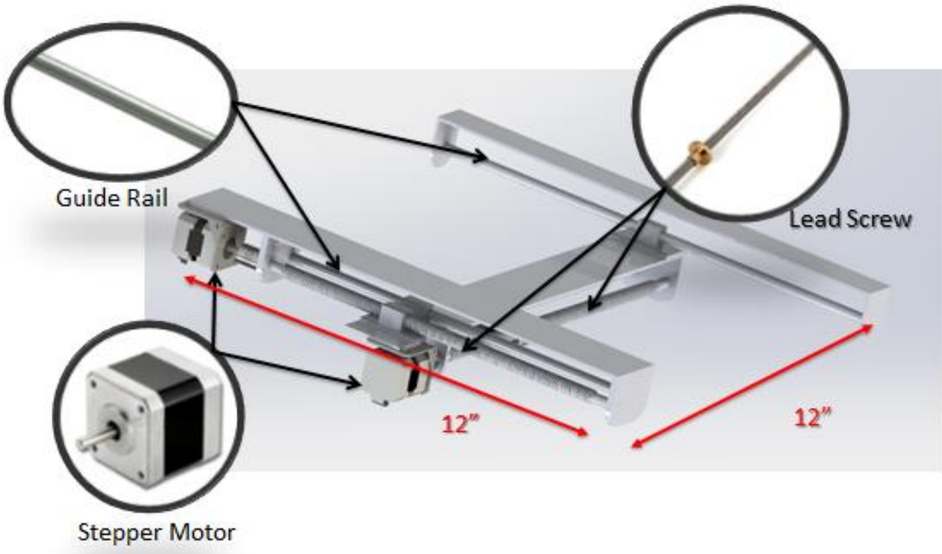


Figure 18 – New Design Translational Movement Visualization

Upon further research and design work, the team determined that the gantry design, shown in Figure 18, would best satisfy the design goals discussed in the previous section. It consists primarily of two linear translation systems which are each composed of a stepper motor to drive the system, a lead screw to take the rotational motion supplied by the shaft of the stepper motor and convert it to translational motion, a shaft coupler to connect the stepper motor to the lead screw, a mounting platform which moves via the lead screw, and support rods to help stabilize the system and guarantee linear movement. As can be seen in Figure 19, one of these systems will allow for linear motion on one axis while the second will be mounted to the first and provide linear motion on the other axis. The marker holder will then be mounted to the platform on the second linear translation system. The gantry will be mounted to the Pioneer 2-DX using square stock tubing and will be positioned in a manner similar to the one shown in Figure 20; additional supports to the top of the robot may also be added in the future as seen fit.

Figure 20 – Mounting Method for New Design

This design is a vast improvement from the previous one in quite a few ways. First of all, as discussed in previous sections, this design, with its platforms for mounting, is far more modular in the sense that altering the design for new marker holders is now effectively as simple as removing the previous design and bolting the new one to the platform. In other words, unlike the previous design, if the team decides to adapt the marker holder design whether it be for a new method of applying pressure to the marker, adding more potential for colors, or switching the marking medium all together (paint, chalk, etc.), this design now allows for that without drastic revisions and virtually no need for changes to the rest of the mechanism. Also, the lead screw coupled to a stepper motor design will be far more accurate than the servo motors coupled to the lever arms as in the previous designs and the system will be more stable due to the nature of the gantry design with the support rods as opposed to the lever arms. As an additional feature, the gantry also allows for the potential to draw shapes with much greater ease should such a feature be desired in the future. With the previous design this was theoretically possible but would have been more difficult to implement whereas with the current design, the system can operate similar to preexisting structures such as 3-D printers and laser cutters, moving the marker holder within the gantry to draw the shapes so long as they fall within the dimensional constraints of the gantry.

3.2.5.4 Ongoing Work

Currently the team is sourcing parts for the gantry design. Primarily the team is focusing on determining what level of pre assembly the system should have. In other words, in terms of cost, modularity, and ease of control, the team is working to determine if it is best to order all of the parts for the gantry separately and assemble it in house, order a preexisting gantry and repurpose it, or somewhere in between. Currently the most likely plan of action the team is going to take is ordering the two linear translation systems and any necessary supports and assembling those into a gantry in house. This setup allows for a higher chance of accuracy and ease of control with the individual linear translation systems in that they are already pre-assembled and proven to work within a specified range of accuracy, while still allowing for an overall modular design of the gantry. Most preexisting gantries are somewhat difficult to alter if the team needs to adjust the mounting locations of all of the components; however, if only the two independent linear translation systems are preassembled, this allows the team more control over how the systems and necessary supports come together to function as the gantry system.

3.3 System Integration

With several components needed to communicate with one another, a microprocessor is used for the physical connections and coding the high level programming. The microprocessor chosen for this project is the Raspberry Pi 2. This 900 MHz quad-core ARM Cortex-A7 CPU with 1 GB RAM memory microprocessor has 40 general purpose input-output pins to connect the two stepper motors from the gantry. The Raspberry Pi also has an Ethernet port that will be used to interface with the Pioneer and call the low level program functions from the Pioneer like movement by coordinates. It will also hold the high level programming that deals with moving the Pioneer to specific locations, and interpreting the position and distance of objects and moving out of the way by the Lidar. Raspberry Pi 2 will also have the API from Trimble allowing the robot to communicate with the robotic total station, giving the precise location of where the marking attachment needs to be for marking. At the moment, the operating system that is used is Windows 10 IoT core OS, so the OS can run the Pointor software and also be programmable to hold the high level program.

3.4 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, multi-step 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 also be found in the Appendix A. This HOQ determined that the team needs to focus on the functionality and the speediness of the final designed robot. Although these may not be the most important, it is something to focus on throughout the design process.

It is important to keep in mind that this will be a proof of concept robot and that we are not currently designing for a final design to sell to consumers but to only prove that the concept of having a single robot plot the lines of a floor plan can exist. Once this has been proven, the focus of the team will be to improve the design in the eyes of the consumers and customers.

4. Results

Following the block diagram shown in Figure 1, team 19 has chosen to use the *Pointor* software to turn the given floor plan into coordinates, combined with the density propagation program which will be run on the Raspberry Pi 2 in order to send the coordinates to the robot. The robot that team 19 will be using is the Pioneer 2-DX which runs on its own operating system, the QNX Neutrino, which will also be communicating to a robotic total station for localization. In order to mark out the layout lines, attached to the robot will be a gantry arm design. Mounted on top of the robot is a LIDAR system, the SICK LMS 200, which the team will use for obstacle avoidance. To illustrate the team's choices in reference to the block diagram Figure 1, a new block diagram has been generated shown in Figure 21 below.

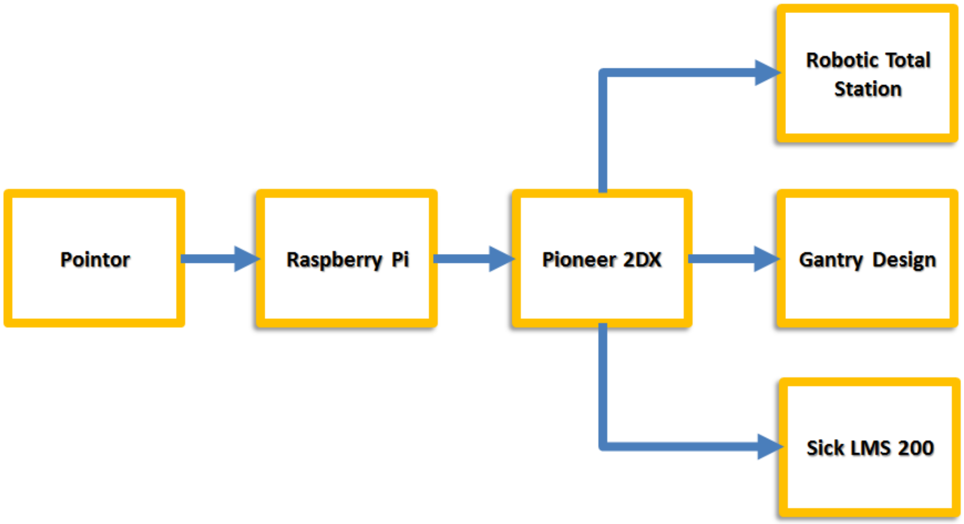


Figure 21 – New Block Diagram

5. Future Work

Team 19 has a lot of work to do in the near future. Next semester will be full of integrating systems together and troubleshooting the code/robot. There will be a mechanical design built and tested first thing. Simultaneously, the team will be working with the Pioneer 2DX to fully understand its inner workings and how to modify it to meet the team's needs as well as integrate it with the gantry design and Raspberry Pi. The team will be working with the LIDAR, Raspberry Pi, and Arduino to understand the integration of the software and hardware. There will be multiple sessions of training/practicing with the Robotic Total Station to fully understand how to integrate it with our system as well.

As for future work with the gantry design, the team will soon begin testing with currently available stepper motors to integrate their control into the overall system of the marking robot to prepare for integrating the gantry once it has arrived and been assembled. Additionally, the marker holder designs will be worked on, focusing on first allowing for three different colors and using the spring loaded system to apply pressure to the marker.

The team is really looking forward to the task of helping change the construction industry by integrating all the previous mentioned technologies.

6. Conclusion

The construction marking robot is a high precision marking robot that will lay out the preliminary floor plan of a construction site. Using a robotic total station the robot is able to ensure continually precise and accurate location, which removes the human error that comes with making the marks manually. A gantry system is used for the physical marking, and is beneficial to our design because it allows for easy replacement of the marking medium for future design improvements. Finally, LIDAR is used on the robot to guarantee obstacle avoidance as both a precaution for the safety of the robot, as well as to providing the information necessary to know what areas of the concrete slab weren’t marked. The robot will be able to increase efficiency and productivity in the construction industry because it is autonomous and can run without human interaction, and is able to reduce the amount of time and error that goes into laying out floor plans manually because it can run continuously and is able to know its exact location real time.

7. References

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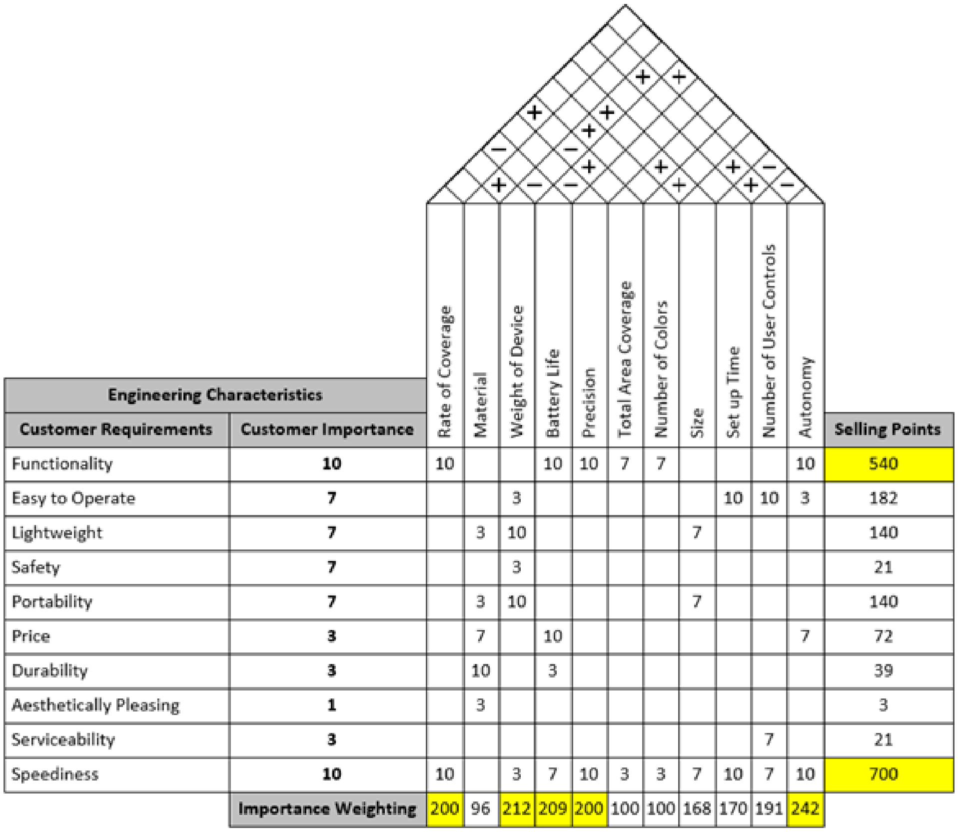
Appendix A



Customer Requirements	Customer Importance	Rate of Coverage	Material	Weight of Device	Battery Life	Precision	Total Area Coverage	Number of Colors	Size	Set up Time	Number of User Controls	Autonomy	Selling Points
Functionality	**10**	10			10	10	7	7				10	540
Easy to Operate	**7**			3						10	10	3	182
Lightweight	**7**		3	10					7				140
Safety	**7**			3									21
Portability	**7**		3	10					7				140
Price	**3**		7		10							7	72
Durability	**3**		10		3								39
Aesthetically Pleasing	**1**		3										3
Serviceability	**3**										7		21
Speediness	**10**	10		3	7	10	3	3	7	10	7	10	700
	Importance Weighting	200	96	212	209	200	100	100	168	170	191	242	

Figure 22 – House of Quality

Importance of Customer Needs Survey

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 sq.ft.

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?

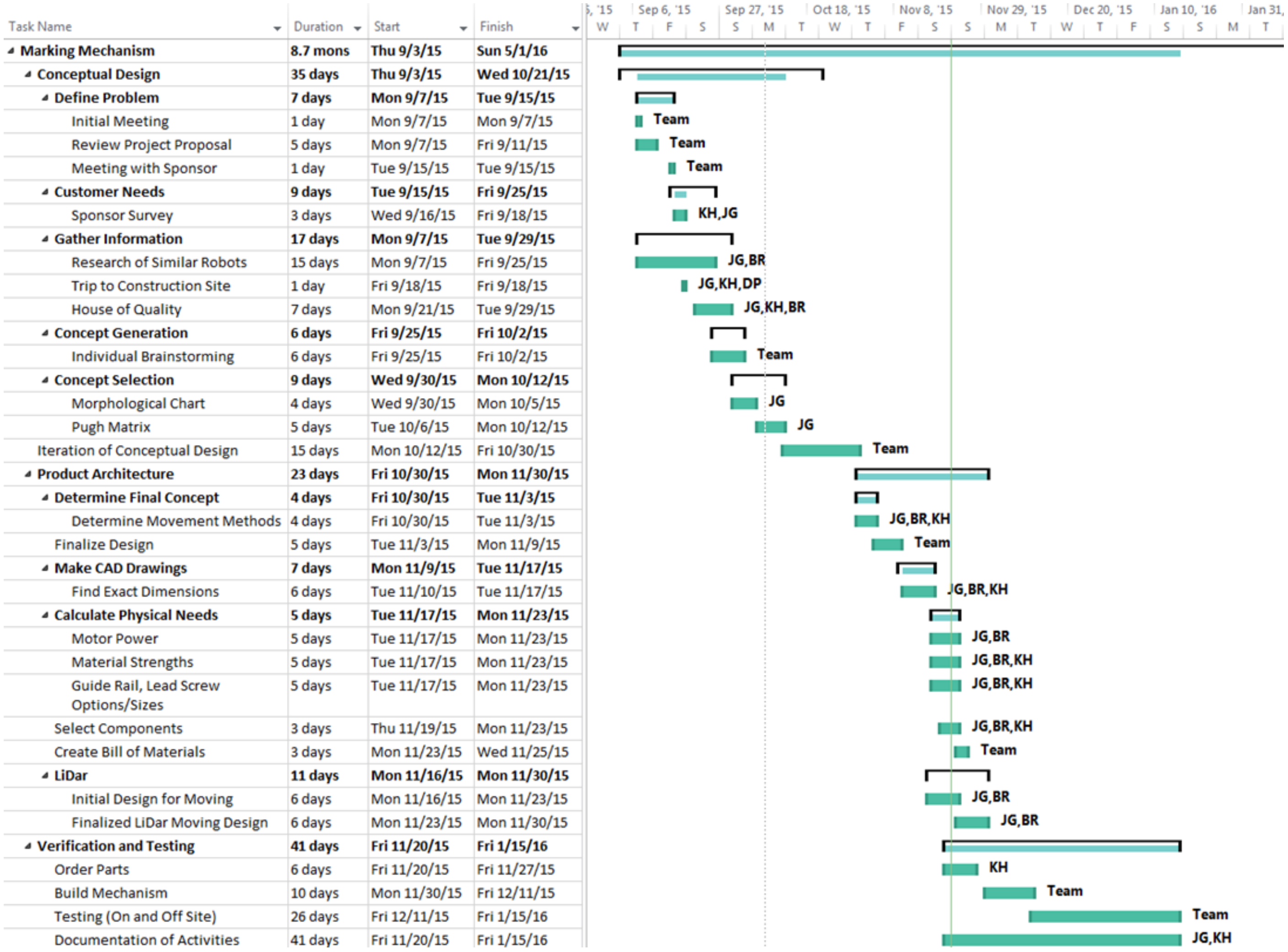
Accuracy 10 ½”

Line continuity 7

Different terrains 3

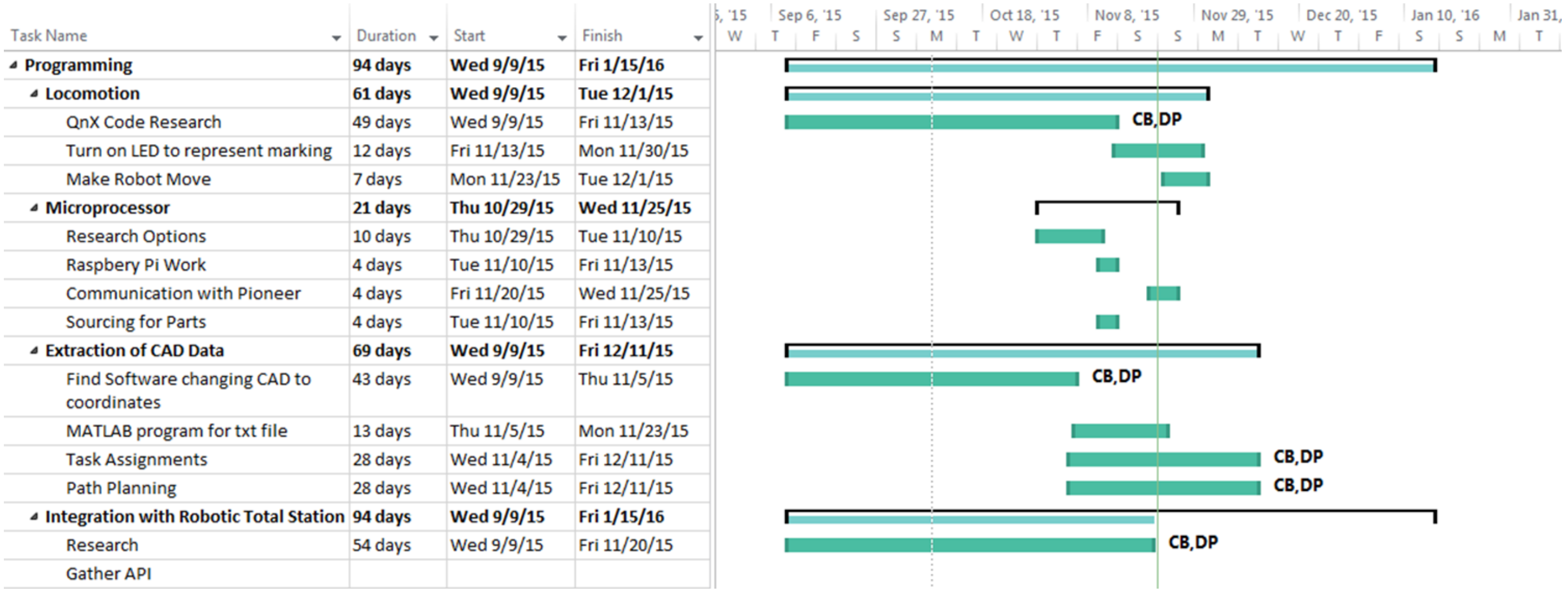
Other uses for robot 4

Sharpie for marking 2



Task Name	Duration	Start	Finish
Marking Mechanism	**8.7 mons**	**Thu 9/3/15**	**Sun 5/1/16**
Conceptual Design	**35 days**	**Thu 9/3/15**	**Wed 10/21/15**
Define Problem	**7 days**	**Mon 9/7/15**	**Tue 9/15/15**
Initial Meeting	1 day	Mon 9/7/15	Mon 9/7/15
Review Project Proposal	5 days	Mon 9/7/15	Fri 9/11/15
Meeting with Sponsor	1 day	Tue 9/15/15	Tue 9/15/15
Customer Needs	**9 days**	**Tue 9/15/15**	**Fri 9/25/15**
Sponsor Survey	3 days	Wed 9/16/15	Fri 9/18/15
Gather Information	**17 days**	**Mon 9/7/15**	**Tue 9/29/15**
Research of Similar Robots	15 days	Mon 9/7/15	Fri 9/25/15
Trip to Construction Site	1 day	Fri 9/18/15	Fri 9/18/15
House of Quality	7 days	Mon 9/21/15	Tue 9/29/15
Concept Generation	**6 days**	**Fri 9/25/15**	**Fri 10/2/15**
Individual Brainstorming	6 days	Fri 9/25/15	Fri 10/2/15
Concept Selection	**9 days**	**Wed 9/30/15**	**Mon 10/12/15**
Morphological Chart	4 days	Wed 9/30/15	Mon 10/5/15
Pugh Matrix	5 days	Tue 10/6/15	Mon 10/12/15
Iteration of Conceptual Design	15 days	Mon 10/12/15	Fri 10/30/15
Product Architecture	**23 days**	**Fri 10/30/15**	**Mon 11/30/15**
Determine Final Concept	**4 days**	**Fri 10/30/15**	**Tue 11/3/15**
Determine Movement Methods	4 days	Fri 10/30/15	Tue 11/3/15
Finalize Design	5 days	Tue 11/3/15	Mon 11/9/15
Make CAD Drawings	**7 days**	**Mon 11/9/15**	**Tue 11/17/15**
Find Exact Dimensions	6 days	Tue 11/10/15	Tue 11/17/15
Calculate Physical Needs	**5 days**	**Tue 11/17/15**	**Mon 11/23/15**
Motor Power	5 days	Tue 11/17/15	Mon 11/23/15
Material Strengths	5 days	Tue 11/17/15	Mon 11/23/15
Guide Rail, Lead Screw Options/Sizes	5 days	Tue 11/17/15	Mon 11/23/15
Select Components	3 days	Thu 11/19/15	Mon 11/23/15
Create Bill of Materials	3 days	Mon 11/23/15	Wed 11/25/15
LiDar	**11 days**	**Mon 11/16/15**	**Mon 11/30/15**
Initial Design for Moving	6 days	Mon 11/16/15	Mon 11/23/15
Finalized LiDar Moving Design	6 days	Mon 11/23/15	Mon 11/30/15
Verification and Testing	**41 days**	**Fri 11/20/15**	**Fri 1/15/16**
Order Parts	6 days	Fri 11/20/15	Fri 11/27/15
Build Mechanism	10 days	Mon 11/30/15	Fri 12/11/15
Testing (On and Off Site)	26 days	Fri 12/11/15	Fri 1/15/16
Documentation of Activities	41 days	Fri 11/20/15	Fri 1/15/16

Figure 23 – Gantt Chart



Task Name	Duration	Start	Finish
◢ **Programming**	**94 days**	**Wed 9/9/15**	**Fri 1/15/16**
◢ **Locomotion**	**61 days**	**Wed 9/9/15**	**Tue 12/1/15**
QnX Code Research	49 days	Wed 9/9/15	Fri 11/13/15
Turn on LED to represent marking	12 days	Fri 11/13/15	Mon 11/30/15
Make Robot Move	7 days	Mon 11/23/15	Tue 12/1/15
◢ **Microprocessor**	**21 days**	**Thu 10/29/15**	**Wed 11/25/15**
Research Options	10 days	Thu 10/29/15	Tue 11/10/15
Raspbery Pi Work	4 days	Tue 11/10/15	Fri 11/13/15
Communication with Pioneer	4 days	Fri 11/20/15	Wed 11/25/15
Sourcing for Parts	4 days	Tue 11/10/15	Fri 11/13/15
◢ **Extraction of CAD Data**	**69 days**	**Wed 9/9/15**	**Fri 12/11/15**
Find Software changing CAD to coordinates	43 days	Wed 9/9/15	Thu 11/5/15
MATLAB program for txt file	13 days	Thu 11/5/15	Mon 11/23/15
Task Assignments	28 days	Wed 11/4/15	Fri 12/11/15
Path Planning	28 days	Wed 11/4/15	Fri 12/11/15
◢ **Integration with Robotic Total Station**	**94 days**	**Wed 9/9/15**	**Fri 1/15/16**
Research	54 days	Wed 9/9/15	Fri 11/20/15
Gather API			

Figure 24 – Gantt Chart

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 Bachelors of Science with plans to move to seeking his Master's degree through the university's BS/MS program, then moving on to industry.