Mini-Project Final Technical Memo

Keenan Schillp, Nicholas Walker, Jordan Palmer

IED Section: 10

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Introduction

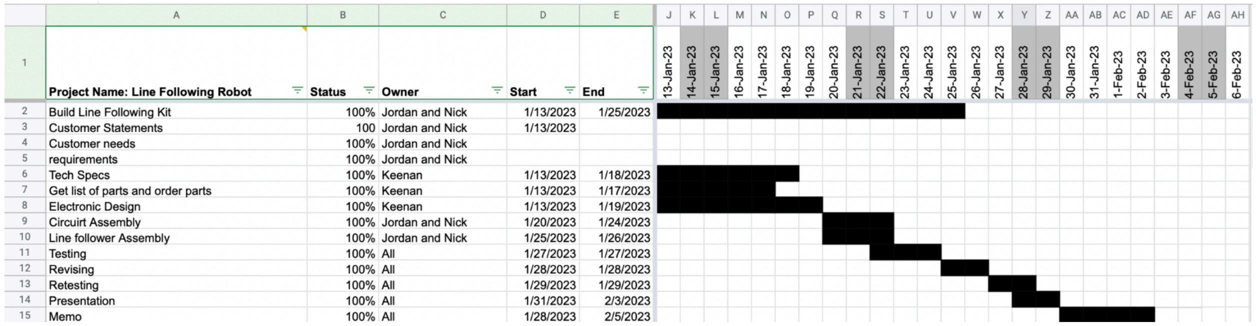
The team designed and created a line follower with the criteria of following a black line on a white surface as well as to complete the nine given courses in a ten-minute time span on competition day. The line follower was also required to follow the path on its own without the assistance of any person via controller or other outside forces during its performance. There would be three unique courses including nine total sections, all with varying difficulty which would test different attributes of the line follower.

Before finalizing the product, the team drafted many designs and experimented with multiple different approaches to ensure that the best possible design would be used. Elements of these designs included the use of an Arduino, sensors, motor shield, and the provided IED line follower kit. Some of the key focuses of the design ranged from speed, aesthetic, and safety providing a product that could be used for nearly all ages.

Concepts and Benchmarking

The first stage of the design process was creating a plan of action within the time constraints of the project. The team created a Gantt Chart to keep track of progress (Figure 1). The design and benchmarking began on 1/13/2023 and finished on 1/28/2023.

Figure 1: Gantt Chart



	Project Name: Line Following Robot	Status	Owner	Start	End
2	Build Line Following Kit	100%	Jordan and Nick	1/13/2023	1/25/2023
3	Customer Statements	100	Jordan and Nick	1/13/2023	
4	Customer needs	100%	Jordan and Nick		
5	requirements	100%	Jordan and Nick		
6	Tech Specs	100%	Keenan	1/13/2023	1/18/2023
7	Get list of parts and order parts	100%	Keenan	1/13/2023	1/17/2023
8	Electronic Design	100%	Keenan	1/13/2023	1/19/2023
9	Circuirt Assembly	100%	Jordan and Nick	1/20/2023	1/24/2023
10	Line follower Assembly	100%	Jordan and Nick	1/25/2023	1/26/2023
11	Testing	100%	All	1/27/2023	1/27/2023
12	Revising	100%	All	1/28/2023	1/28/2023
13	Retesting	100%	All	1/29/2023	1/29/2023
14	Presentation	100%	All	1/31/2023	2/3/2023
15	Memo	100%	All	1/28/2023	2/5/2023

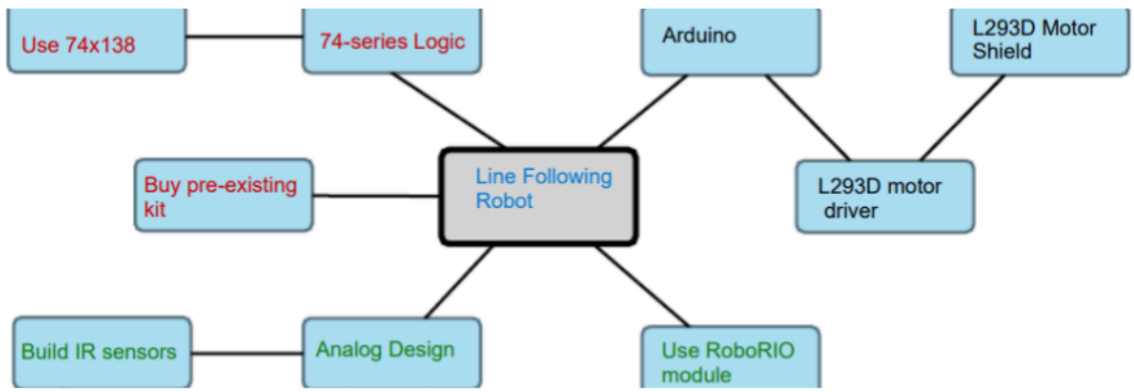
The team began the design process by interviewing potential customers to see what they would want in a line-following robot. The customers were children of age 5 to 12 and their parents. After interviewing the customers, the team drafted metrics and technical requirements to meet their specifications. This feedback is summarized in Table 1.

Table 1: Customer Needs Interpreted

Customer Need	**Priority (Scale: 1-6)**	**Metric**	**Technical Specification**
Speed	5	Speed following line (ft/sec)	Drive at least 1 ft/sec
Ease of use	2	Time to turn on (sec)	Turn on in below 5 seconds
Durability	4	Full functionality after use	Follow course over 20 times without breakdown
Battery Life	6	Long battery life	Over 20 minutes of battery life on single charge
Safety	1	Safe for children to hold	No exposed wiring or charged surfaces
Cost	3	Cheap to buy for child	Build cost below $30

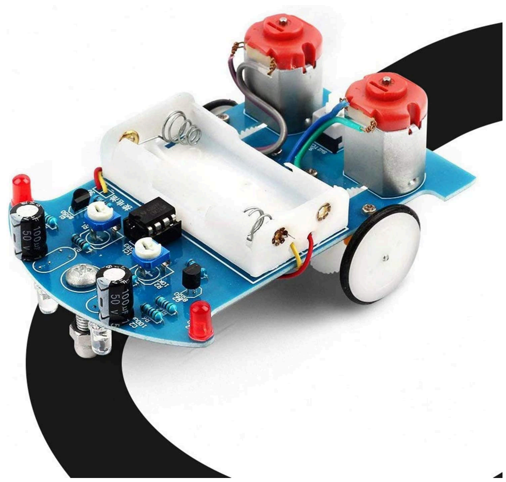
Using this as the baseline, the team started to brainstorm ideas about how the team could also make the design small, compact, and easy to use while attempting to resolve any issues present. To do this, the team created a brainstorming mind map (Figure 2), which lists some possible designs, and some intricacies of each design. These designs included using an Arduino and implementing code to run the robot, using a 74 series logic chip design, and finally using an analog design.

Figure 2: Mind Map



To see similar products to the intended design, the team looked online for a line-following robot with similar functionality. The team found the Mioyoow Line Following Robot (Image 1), which was benchmarked by reading online measurements, specifications, and tests. This design proved the validity of the IR sensor-based design, but it failed to be efficient with its usage of the battery pack and motor driver.

Image 1: Mioyoow Line Following Robot



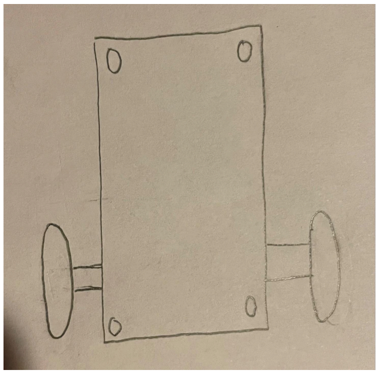
After observing a similar product, the team created a concept selection matrix that compared three possible designs to the existing product. Possible designs were broken up by each customer requirement, as well as overall appearance. Concepts were scored from -2 to +2 based on the comparison to the existing product. After comparing different concepts, an Arduino based design was chosen by the team because of its' simplicity in design, as well as its' increase in power.

Table 2: Concept Selection Matrix

Selection Criteria	Arduino	74-series Logic Chip Design	Analog Design	MiOYOOW Line Follower (existing)
Speed	+1	-1	-1	0
Ease of use	+1	+1	-2	0
Appearance	+2	-1	-1	0
Durability	+1	0	-1	0
Battery Life	+2	+1	-1	0
Safety	0	-1	-1	0
Cost	-1	0	+2	0
Sum	+6	-1	-5	0

These concepts were selected and broken into sub-components, which allowed for the separation of different parts of the design. The first was the robot chassis, which held the wheels and motors as well as the rest of the design. A sketch (Figure 3) was created of the chassis to picture a general design.

Figure 3: Chassis Sketch



The second sub-component was the motor controlling circuit, which included the motor shield, the motors, and the Arduino control. The third sub-component was the sensing circuit, which included the IR sensors, tuning potentiometers, and Arduino sensor input. The components were laid out using initial sketches (Figure 4/5) shown below:

Figure 4: Bottom View

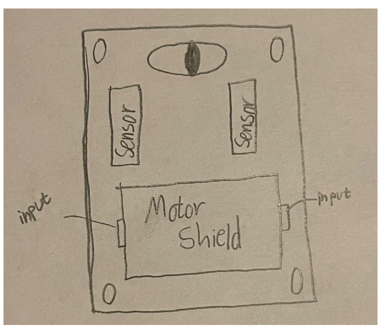
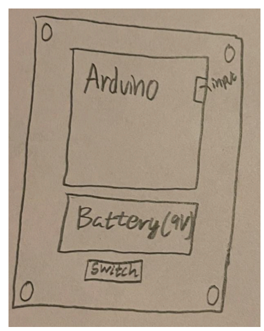


Figure 5: Top View



Lastly, the final sub-component was the Arduino code. Before code was written, a block diagram (Figure 6) was created to map the process of the code and the signal propagation through the circuit that was to be assisted by the code.

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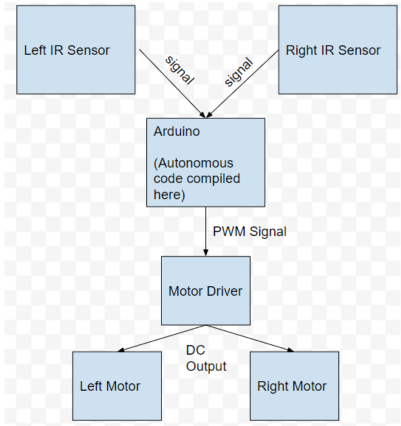
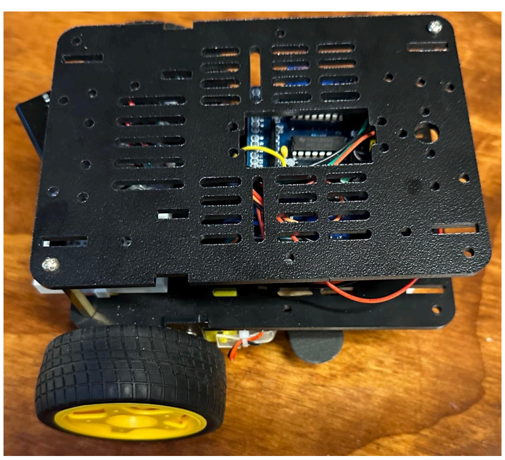
Figure 6: Arduino Code Block Diagram



Solution

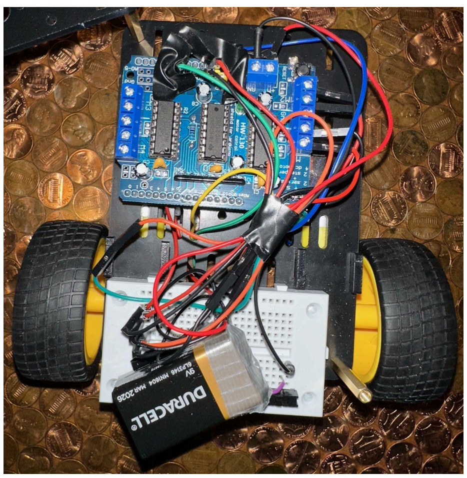
Based on the team's research, customer requirements, and concept selection matrix, the team decided to use an Arduino-based design. The main elements of the design were the chassis, motor control, sensing, and code. First, the chassis was designed to make sure that all the components would fit. Then, the chassis (Image 2) was built and the motors added to create the base to put the circuitry on. A design with a wheelbase of four inches was selected to minimize the turning radius while leaving room for the components inside the chassis.

Image 2: Robot Chassis



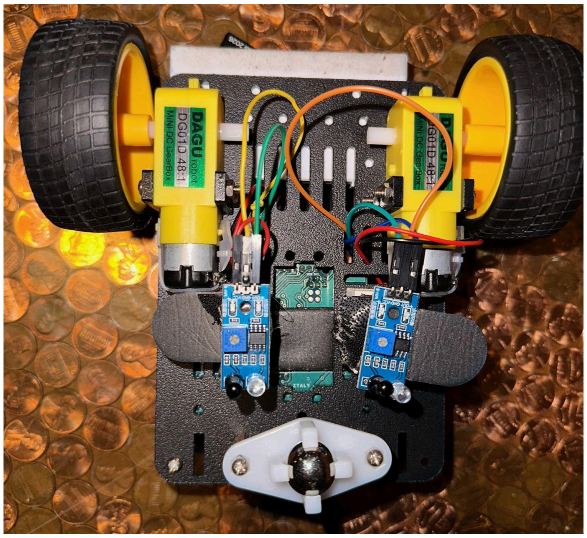
Next, the motor controlling circuit (Image 3) was constructed, which connected the motor drivers to the motors and the Arduino. The L293D motor shield was selected to drive the motors based on its' compatibility with the Arduino as well as the cost and ease of use. The L293D was wired to the Arduino, and then subsequently powered and wired to the motors. A separate battery was used for the motor driver and the Arduino. This allowed for the battery to last longer since an individual battery was only controlling either the sensing or the motor controlling circuit.

Image 3: Motor Control Circuit



The sensing circuit (Image 4) was then constructed with two IR sensors mounted to the base of the robot, pointing downwards to pick up the line on the ground. To minimize error, the sensors were placed ⅛" away from the ground. This allowed the sensors to pick up a stronger signal at this close distance. The sensors were then given an initial calibration to be adjusted in further testing.

Image 4: Sensing Circuit



Finally, the code was written and implemented for the robot to propagate and process the signal from the IR sensors to create the intended motor output.

Test Plan and Test Results

Throughout this process the group faced quite a few obstacles. The first of these issues came with the actual testing of the robot itself as finding surfaces to practice on proved to be difficult needing a light enough surface. The team started out testing on tiles in one of the member's Rahps A apartments, however, the marble wasn't a pure enough color and consisted of bits of gray and black. The solution to this problem was to conduct the test on pieces of white paper that would be taped together and the course would be put on the paper via black electrical tape. Another obstacle the team encountered was the batteries. Replacing the batteries would throw off the range of the two sensors at the bottom of the line follower causing us to realign it every time.

The team began its testing by calibrating the IR sensors that the team used to detect the line. This involved changing potentiometer values in the design to change the frequency of the signal that the IR sensor was transmitting. This allowed the team to get the sensors to be calibrated to the specific color of the tape to allow for a difference in logic levels between the tape and the white track. After this, the team ran the robot to verify that the motor output levels matched the speed and direction the team wanted to output. Once this was verified, the team put the robot on the test track to verify that it was following the line.

To make sure the team fulfilled the project requirements, verification that the project was safe was shown by testing voltages on different outer components. These tests proved that the components were not electrically charged. When the car was placed on the testing tracks and ran through the tracks. With sensors calibrated, the team tested the robot with differing speeds around the tracks and plotted the failure rate versus speed for each of the courses below. These tracks were in the shape of an octagon, infinity symbol, and straight line. The completion rates vs. speed for each course were plotted (Figures 7, 8, 9) to determine the optimal running speed.

Figure 7: Octagon Completion Rate vs. Speed

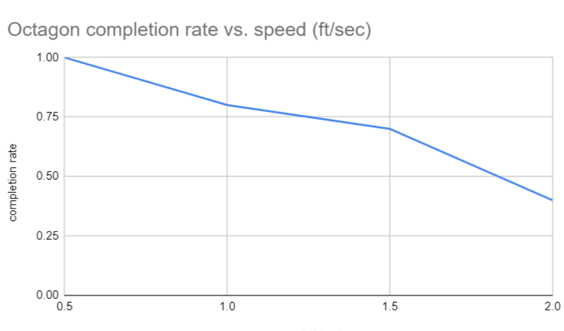


Figure 8: Infinity Completion Rate vs. Speed

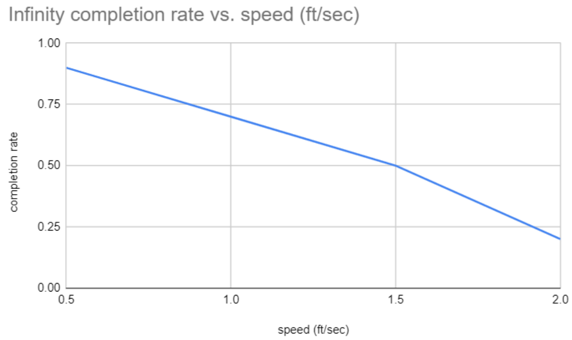
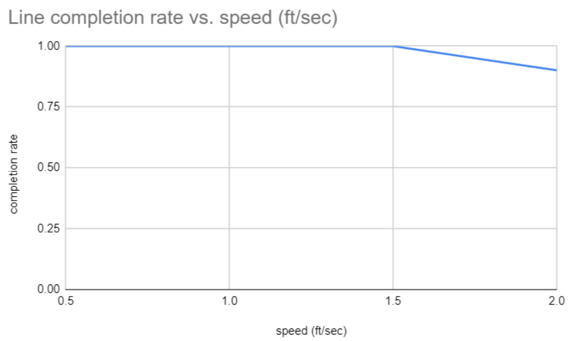


Figure 9: Line Completion Rate vs. Speed



After this testing, the team concluded that for all the courses except the straight line course, speed needed to be lessened to reduce error. With a final set speed of 0.75 ft/sec, the team were able to find a good medium between error rate and speed. This allowed us to complete the courses fast while maintaining a low error rate.

Table 3: Competition Results

Course 1 (Beginner)				**Course 2 (Intermediate)**				**Course 3 (Advanced)**		
section	time (sec)	errors		section	time (sec)	errors		section	time (sec)	errors
1	6	0		1	4	0		1	Unfinished	5
2	8	0		2	6	1		2	7	1
3	9	0		3	5	0		3	Unfinshed	4

During the competition the line follower performed incredibly well overall completing seven of the nine possible courses. For the beginner course the product hit the mark with ease and completed it in its first attempt. On the second course the line follower had a slight error on the second section, however without changing anything it succeeded on the second attempt. Finally on the third attempt the line follower began to struggle as it could not complete the smallest turns implemented in the advanced course. Despite cruising courses prior, the line follower could not complete the small semi-circle turns of the advanced course. The team had lots of time to spare from completing the first two courses so quickly and was able to reprogram the speeds of each wheel using the Arduino software, however, the line follower still fell short despite the pit-stop speed adjustment and only was able to complete one of the advanced sections and scored a 94%.

Conclusion

"Gertrude", the line following robot, was created to meet the requirements of 5-to-12 year old children and their parents wanting a toy for their child. These requirements were then distilled into technical specifications, which were benchmarked with existing products. After this analysis, an Arduino-based design was selected. Once this design was determined, sub-systems were chosen and design for those was completed. The robot was then fabricated, programmed, and calibrated to become ready for testing. After testing, it was determined that the robot should run at a speed of 0.75 ft/sec, and this allowed for the maximum speed with minimization of error.

During the competition, he project worked to near perfection, only faulting twice and earning a 94% on competition day. The line follower boasted an incredibly fast speed through the intermediate course at fifteen seconds (much faster than average). This aspect clearly differentiated this design from the other competitors against the benchmark and gave the device a unique feature and ability. When the final design of the product was finished, the team polished the design with a cap to cover the top of the line follower, hiding any loose wiring from above and giving the robot a more aesthetically pleasing look.

Overall, the final design of the line follower achieved its purpose and excelled in many key components that the team valued important. Safety for this product was a must as it was geared towards children and this requirement was met completely. The team was satisfied with the results and the product.

Lessons Learned

Throughout this project the team learned many lessons, many of which can be useful for future projects. The most important of which was to be prepared for setbacks. The team came across several obstacles and redesigns throughout the process and in total cost the team a few additional days to complete the product.

Another key lesson learned was to think outside the box. A key component of that would have been to use a different kit than the class provided in order to obtain a more precise final product. This focus for future projects will definitely be implemented as it will allow for future projects to be more specialized and alleviate any limitation that may possibly be exposed.

The team learned to prepare more effectively for team meetings by being aptly prepared for the discussions that were to happen. Team meetings ran much more fluidly when the discussion topics were determined beforehand so that each team member could come with something to bring to the table. This allowed for faster, more productive meetings.

A final key lesson learned was a better understanding of engineering organizational structure. Through collaboration in teams and official writeups, the team learned that engineering doesn’t just happen in the lab. The team worked to create documentation that was for the organization within which we are working, which is an essential skill for any job. Engineers are constantly tasked with explaining their work to others so that it may be applied in the real world by those who may not understand the design completely. The ability to work under an organization and write documentation that explains to someone not involved with the project the function of it will prove to be valuable for the upcoming team project and beyond.

References

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- “Line Following Robot Cartoon Transparent PNG - 488X250 - Free Download on Nicepng.” *NicePNG.com*, https://www.nicepng.com/ourpic/u2e6r5t4o0u2y3u2_line-following-robot-cartoon/.

Appendix - Software / Technology Used

Collaboration Among Team Members

- Webex Teams
- Apple iMessage

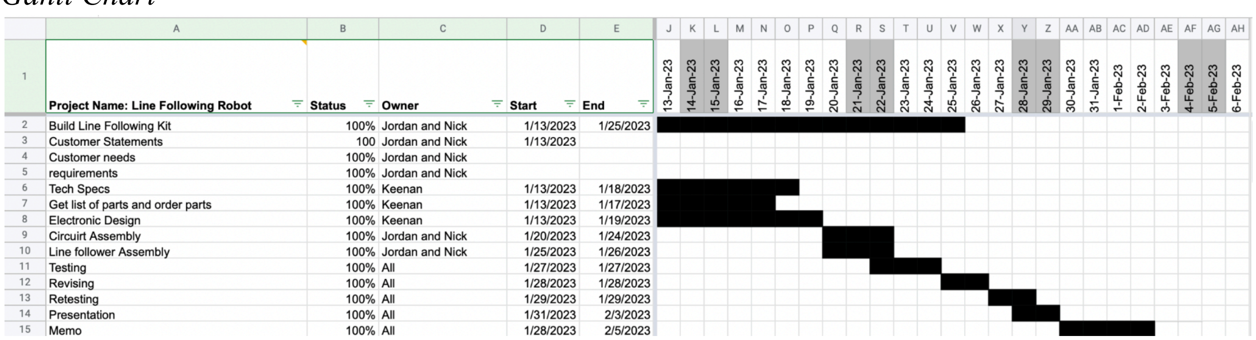
Design

- LTspice – for schematics and simulation

Programming

- Arduino IDE

Gantt Chart



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