ECE 4950: Final Design and Implementation
AATOF

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Due: December 11, 2020

Executive Summary:

The purpose of this project was to develop the final robotic design as required by the customer, and to provide proof of concept via a demonstration of said robot. In order to ensure customer satisfaction with the final product, the customer requirements were directly mapped to engineering requirements. The students were tasked with producing a usable interface to allow a user who is unfamiliar with programming to provide instructions to the robot. The robot would then have to enact the desired pattern implemented by the user into a series of coherent movements to enable the electromagnet to move the washers into the prescribed pattern on the gameboard. Due to the competitive nature of this design process, it was to the benefit of the students to simplify the algorithm as far as possible to minimize the number of discrete movements required, thereby reducing the time required to complete a given pattern. Once the prototype was completed and constructed, testing was able to begin and the students were able to observe how well the robot was able to meet the requirements provided. The students also produced a final Gantt chart detailing the progression of the project through all four phases required by this assignment, as well as the general workload assigned to each individual team member.

Final Engineering Requirements from Given Customer Requirements

- The robot must be able to move autonomously with no human interaction once a pattern has been specified in the user interface.
- All provided components must be incorporated into the final system in the appropriate locations.
- Total cost for all components of the robot, excluding the laptop used to interface with the robot, which is assumed to be already owned by the user, costs less than $300
- Power is supplied, via an AC to DC converter, from standard 120V AC found in households in the US.
- The system should be able to perform the same operation several times in a row.
- The system should still operate correctly after multiple operations
- No hazards exist that are frequent, probable, occasional or remote with a severity rating of critical or catastrophic, as per the analysis performed in the previous section of this project.
- No hearing protection is required to maintain safe noise levels during operation.
- No rotational or shock hazards are present to the casual user.
- Rotation speed at least 4 rads/s
- Simple input format for the user
- A user with no prior knowledge of the system is able to operate it.
- All components are readily available from online sources and are not custom-built or special order devices.
- The robot is able to complete tasks with no human interaction.

System Architecture

Electrical Components

In order to power the Arduino, it was connected to a 12 V external power supply. Additionally, the Arduino was connected to a laptop via a USB A/B cable. The magnet circuit seen in figure 2, which was created for project 1, was used to control the electromagnet. This circuit allows the electromagnet to be powered while preventing back current from entering the Arduino. The circuit was built using a breadboard, allowing for quick changes to be made during prototyping.

With the system mostly built, the next step was to implement the motor so that the gameboard could rotate its position according to the program's algorithm. However, the code was written to take the shortest path possible. In order for the physical system to be able to match the decisions made by the code, the motor would need to rotate in both directions but can only do so with the help of a motor driver. To remedy this, an L298N motor driver was purchased and incorporated into the system to give the motor the flexibility to rotate in both directions.

Since the group used a 12 V power supply into the arduino, the input voltage (Vin) was connected to the L298N so that the motor can be powered and any other low-powered electronics connected are not affected by the source. The output, of the motor driver, is then connected to the motor so it is sufficiently powered. With the components connected, the system was given power to ensure that they functioned by themselves so that they were not an issue in further project development.

The cost of the electrical components used include $0.20 for two 1k ohm resistors, $17.05 an L298N motor driver, $38.50 for an Arduino mega, $12 for 12V external power supply, $0.20 for an IN4001 diode, $0.22 for a 2N3904 npn transistor, $2.90 for the breadboard, and $1.95 for a set of 20 wires. This results in a total cost of $70.12 for the electrical components. All of these prices come from Digikey.

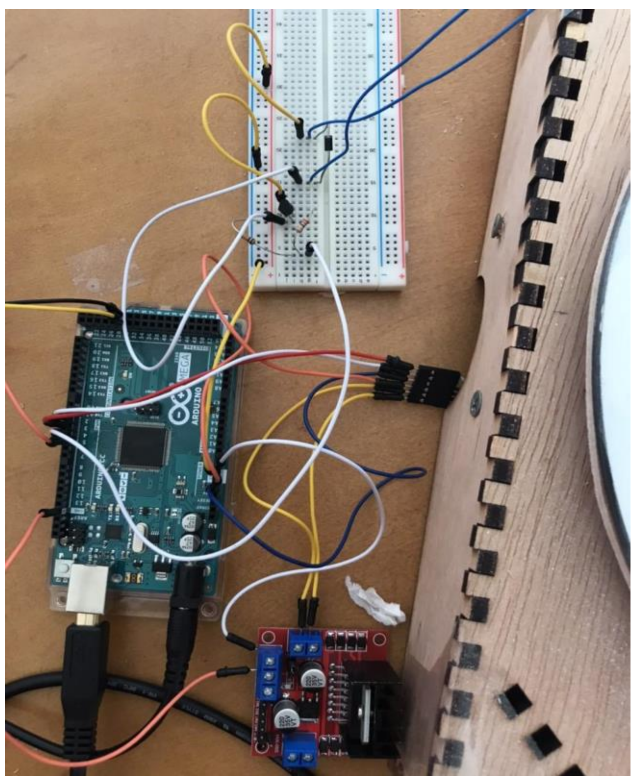

Figure 1: Final Circuit

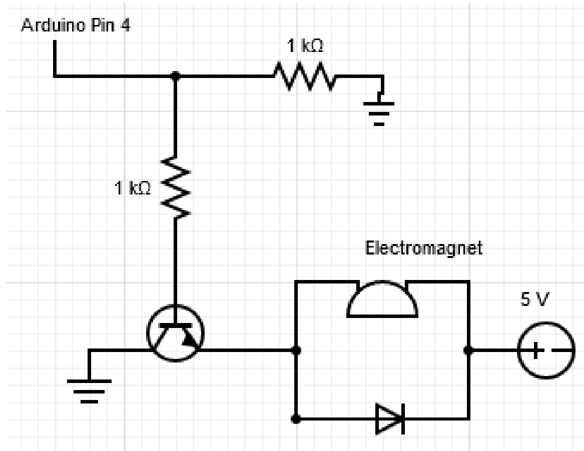

Figure 2: Electromagnet Circuit

Mechanical Components:

The overall system consists of a box to house the motor and support the stands for the electromagnet and camera, and a circular game board attached to the motor shaft, via epoxy, so that the gameboard is centered on the box. It is also critical that the gameboard is assured to be level at this stage, otherwise tuning the system to pick up only the intended washer will be much more difficult if not impossible. The game board will rotate and move the wells to be directly under the electromagnet. In order to help background subtraction the top of the game board was painted white. A stand for the electromagnet is attached to the center of one side of the board. This stand will hold the electromagnet 30 mm from the end of the box. This will result in the magnet being directly over the wells. A stand to hold the camera is attached to the opposite side of the board. This stand will be 900 mm tall and suspend the web camera over the center of the game board. The camera is this high so that it can have a clear view of the entire game board. The exact dimensions of this design can be seen in figures 4 and 5. In addition a picture of the final system can be seen in figure 3.

The cost of the wooden parts of the system include: $5 for the box, $2 for the gameboard, $0.5 for the electromagnet stand, and $4 for the camera stand. In addition $4 for the white spray paint. These prices came from Home Depot. The prices for the mechanical components of the system include $29 for the 12V DC motor, $7.50 for the 5V electromagnet. These prices came from Digikey. This results in a total cost of $52.

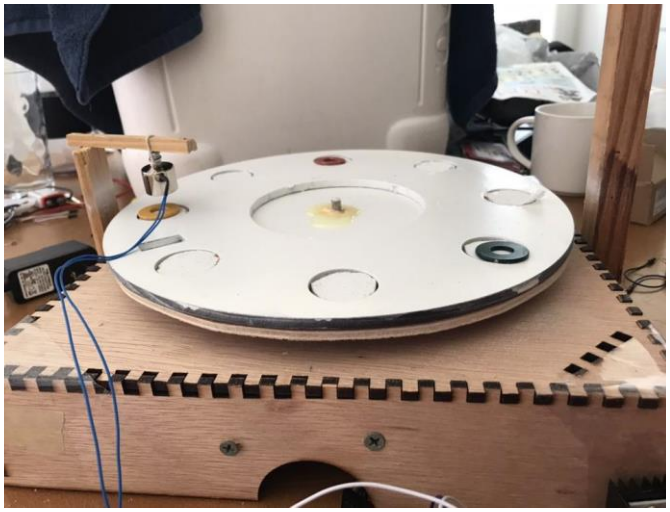

Figure 3: Picture of the Final Design

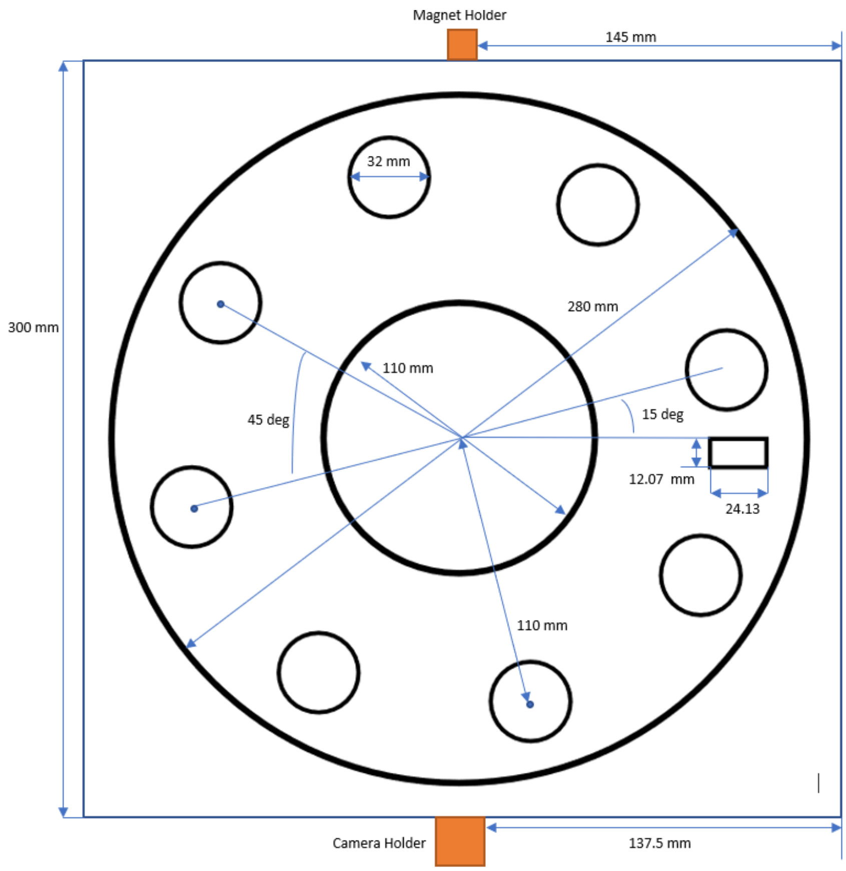

Figure 4: Overhead view of the device

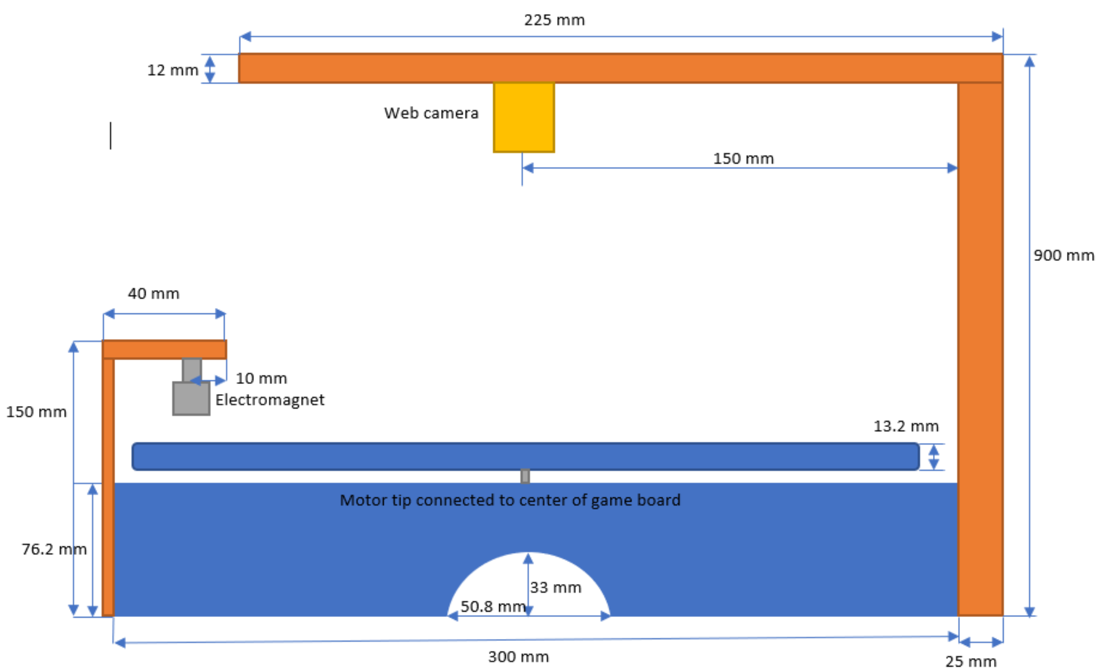

Figure 5: Side view of the Device

Software Components:

The Docooler USB 2.0 HD Camera takes pictures that are 640 x 480 pixels. Two pictures need to be stored, one for the background image and another to calculate the current game state, thus the device needs 614400 pixels. With 8 bits per pixel this results in the system needing 614.4 KB to store these images.

Matlab and simulink were used to implement this system. Matlab was used to create the GUI, to perform background subtraction, and to calculate how to sort the washers. The simulink diagram used can be seen in figure 7. To program the Arduino the simulink code was converted to c and the Matlab code was run on a real-time workstation.

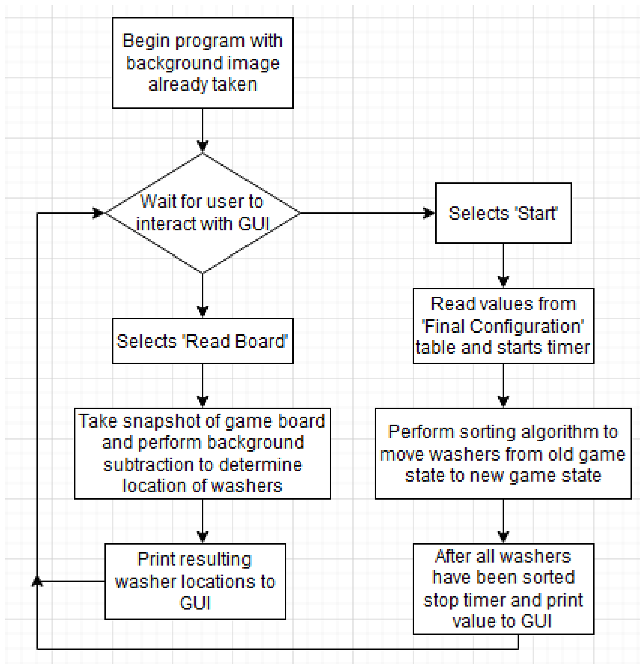

Figure 6: Flowchart for Washer Sorter Software

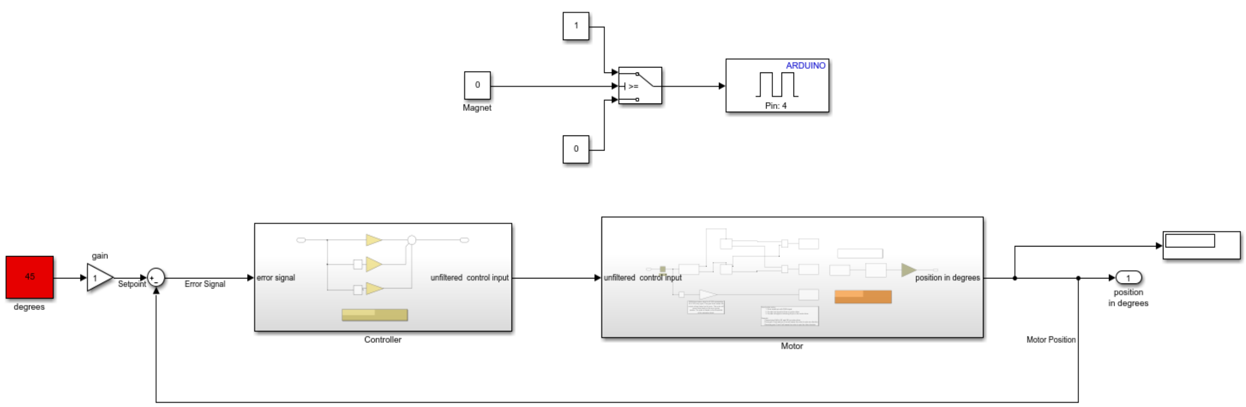

Figure 7: Simulink model for both closed-loop motor control and electromagnet activation

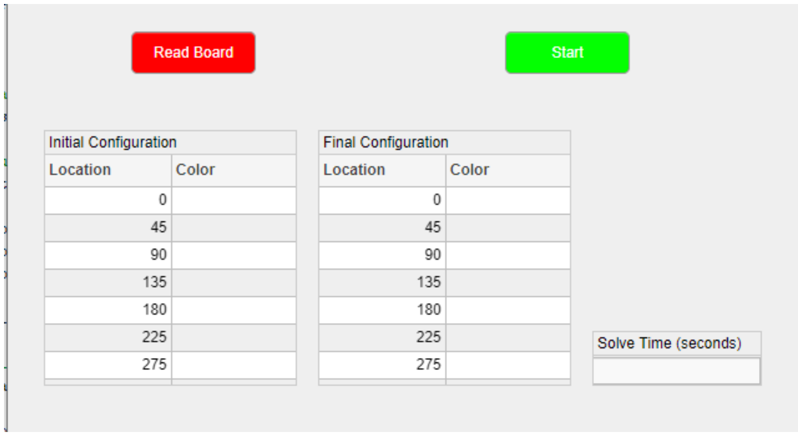

Figure 8: GUI for Motor System

The data structure created for this project is named gamestate and contains the following information:

gamestate.loc	(x,y) pixel location of every colored sticker centroid
gamestate.angle	Angle in degrees of every colored sticker
gamestate.color	Color of every sticker
gamestate.back_Orig	Background Image (game board without stickers)
gamestate.current	Original Image (game board with stickers)
gamestate.diff	Background Subtraction Image
gamestate.diffrem	Binary Background Subtraction Image

Testing of the image processing software involved taking a background picture, then placing various combinations of washer placements. These placements include placing one washer of each color on the board, placing multiple washers of the same color on the board, placing washers of the same color adjacent to each other, and across the board from each other. For each of these combinations background subtraction was performed and the result was printed to the GUI in the ‘Initial Configuration’ table. It was then verified whether background subtraction had succeeded or not.

To test the software for the system the simulink model was disable to prevent the motor and the magnet from turning on. Then a typical session of the system was performed. That is a background image of the board was taken followed by placing washers on the board. Then the GUI was started and the current gamestate was read. After this a new combination of washers was inserted into the ‘Final Configuration’ table.

The cost to implement this software was the cost of a Matlab license and $16 for the camera. An annual license costs $860 and a perpetual licence costs $2,150. The students were able to implement this license for no additional cost as the University provides an academic version of the software for use by all students while attending Clemson University. Thus the costs for the software components was $16.

System Integration

The total cost for the entire system was $122.12.

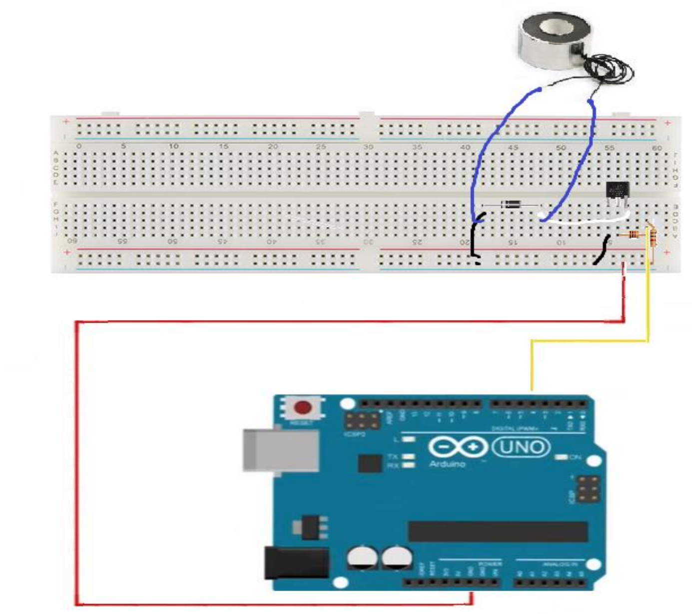

Figure 9: Electromagnet Wiring Diagram

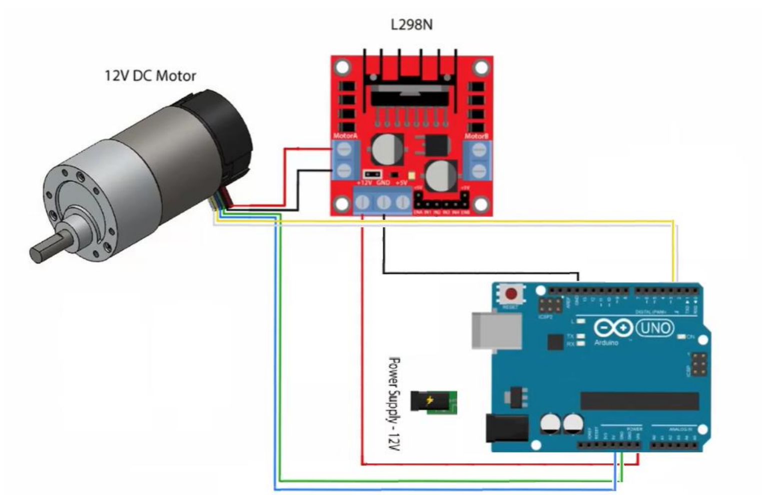

Figure 10: Motor, Motor Drive, and Arduino Wiring Diagram

Analysis of Final Prototype Performance

This project failed to meet the customer requirements. The main reason for this was that the electromagnet was not able to generate an electric field strong enough to pick up the washers at a distance of greater than 3 mm. During testing it was found that the electromagnet heated up considerably while still failing to lift the washer from any height greater than 3mm. This is likely due to either an internal fault with the device, or too much current being applied to the electromagnet. The electromagnet was also observed to have developed discoloration around the center where the screw is to be attached as seen in figure 11, this likely being due to overheating. Given the late stage in development that this issue was discovered, sufficient time to acquire the necessary components to correct the issue and test the robot again was unavailable. Even were the electromagnet to be replaced, the design criteria would not be met, as not all of the provided components would be used.

Figure 11: Electromagnet Discoloration

In addition, the camera was too far away from the gameboard, causing the background subtraction to work intermittently due to the large area that had to be processed, and rarely for the yellow washers. The inability for the background subtraction to work consistently could also be attributed to the color of the gameboard being white - a different color may have provided more contrast. The system had a difficult time differentiating between yellow and white since their RGB values were too similar.

The main cause of the problems with the electromagnet/washer interfacing and the game board's stability was a failure to create a detailed enough design. A more detailed design prototype should have been created as an intermittent step that would have evidenced problems like these, enabling sufficient time to be allotted for their correction. The height of the camera was caused by a lack of clear communication between group members. Detailed measurements should have been drawn up and used to place the camera over the gameboard.

Robot plays the game according to the rules.	The robot is able to simulate playing the game but it is unable to actually pick up the washers.
Uses game stage, including computer, electrical and mechanical interfaces	This device uses game stage, including computer, electrical and mechanical interfaces
Costs <$300	Total cost is $52 by the breakdown in the "Mechanical Components" section above
Use provided Arduino, camera, magnet, and motor	All of these devices are used in the final project
AC Power/ No batteries	An AC power supply was used with an AC-DC converter
Reliable	Background subtraction is only reliable for the red and green washers.
Durable	Glue/epoxy holding motor and board together comes apart after several uses.
Safe	Noise levels do not require hearing protection and there are no sharp corners.
Fast Solving Times	The total time from when the user input the desired final pattern to when the motor stopped moving did not

	exceed 1 minute for any test case used.
Easy to use/user-friendly	User is shown descriptive buttons and tables
Electric/electronic circuits built from off-the-shelf components	All components were off-the-shelf components
Runs automatically	After pressing start the device will ‘sort’ the washers with no human input.

Washer Sorter

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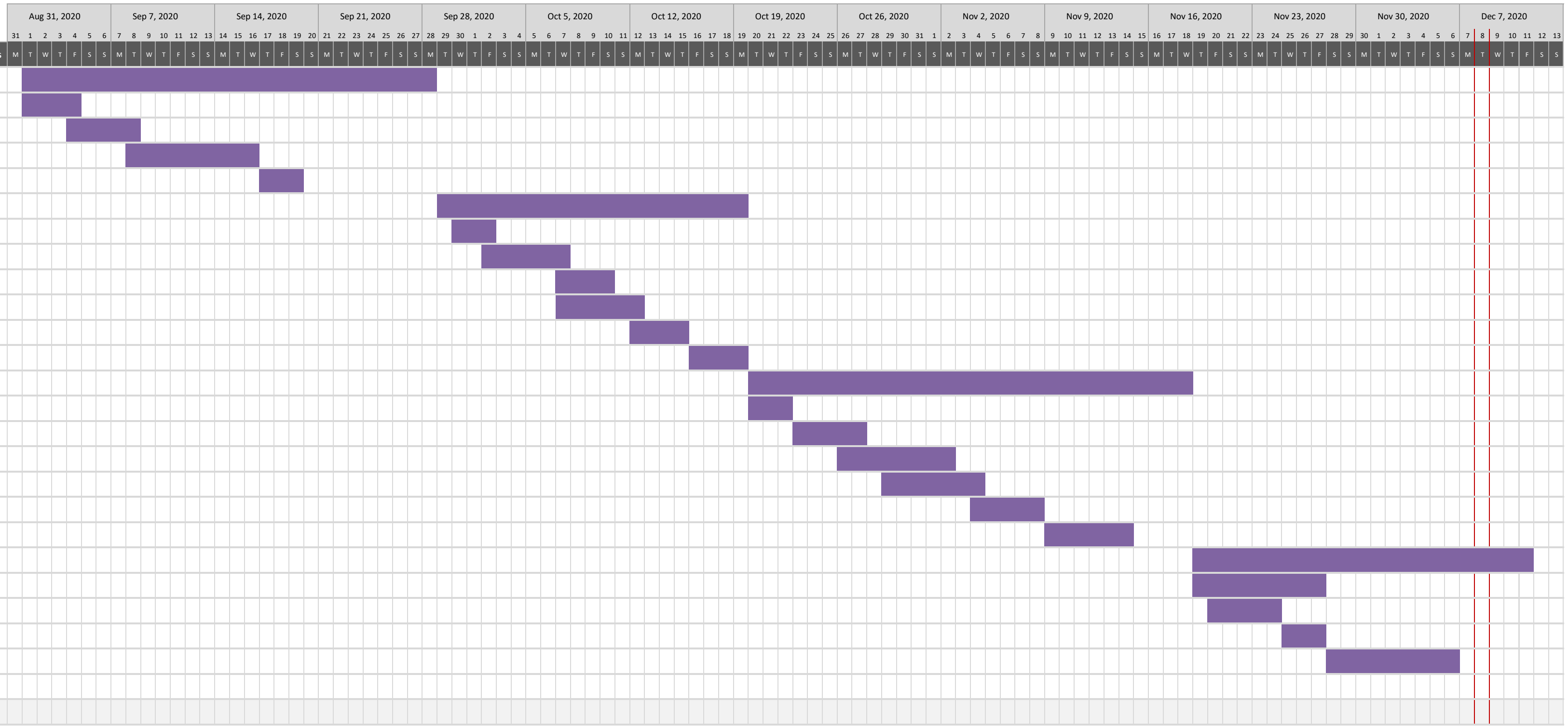
Tue, 9/1/2020

1

TASK	START	END	DAYS
Configure Real-Time Workstation	9/1/20	9/28/20	28
Configure Real-Time Workstation to intreface with Arduino and Matlab	9/1/20	9/4/20	4
Connect Electromagnate to Arduino	9/4/20	9/8/20	5
Create Simulink File to Controll Electromagnate	9/8/20	9/16/20	9
Design Acrylic Part	9/17/20	9/19/20	3
Camera as a Sensor	9/29/20	10/19/20	21
Brainstorm Possible Designs	9/30/20	10/2/20	3
Review Ideas and Make Selection	10/2/20	10/7/20	6
Build Reduced-scale Mockup	10/7/20	10/10/20	4
Create Matlab File for Background Subtraction	10/7/20	10/12/20	6
Setup Camera as a Sensor	10/12/20	10/15/20	4
Test Camera as a Sensor	10/16/20	10/19/20	4
Motor Closed-loop Control	10/20/20	11/18/20	30
Connect Motor to Workstation	10/20/20	10/22/20	3
Hardware in the Loop Testing	10/23/20	10/27/20	5
Build Prototye of Device	10/26/20	11/2/20	8
Design Simple Matlab UI	10/29/20	11/4/20	7
Design Matlab Function for Motor	11/4/20	11/8/20	5
Test Motor Closed-loop Control	11/9/20	11/14/20	6
Final Design	11/19/20	12/11/20	23
Build Final Prototype	11/19/20	11/27/20	9
Design Sorting Algorithm	11/20/20	11/24/20	5
Design Full Matlab UI	11/25/20	11/27/20	3
Test Final Product	11/28/20	12/6/20	9



ECE 4950 Project 4 – Customer Requirements and Final Design Parameters

Use the guidelines below to complete your report and add at the end of your report.
Group Member Last Names: Dreitzler, Prioleau, Pham, Reaux, Severance

Score	Pts		Performance Indicators
	5	**General Format - Professional Looking Document/Preparation (whole document)** a) Fonts, margins (11pt, times new roman, single spaced. 1" margins on all sides). b) Spelling and grammar are correct c) Layout of pictures – all figures need numbers and captions and must be referenced in the text d) Follows the page limitations below. e) References. Use IEEE reference format. f) This grading sheet is included as the final page.	g.1
	0	**Page 1: Title, Group Name, Group Members, and Date** **Executive Summary** (1 concise, well-written paragraph) Provide an overview of this project. Briefly describe what you did and what you learned.	g.1
	5	**Page 2: Engineering Requirements** (<1 page) Bulleted list of Final Design Engineering Requirements	e.1
	10	**Pages: 3-7: Design Details (<5 pages)** Describe a system that can be built including System Architecture and System Integration based on the Engineering Requirements. Do not include data sheets or software code.	e.2
	10	**Page 8: Analysis of Final Prototype Performance** (<1 page) Did it succeed or fail to meet customer requirements? What went wrong and what happened in the design process to allow this problem? Make a table of the customer requirements and address how well your design met these expectations.	e.3 e.4 i.1
	5	**Page 9: Project Schedule/Gantt Chart** (<1 page) Create a schedule (Gantt chart) that shows the tasks and schedule for your project. Start from the very beginning of your project and extend to the end (completing final report and presentation).	k.2
		Page 10 This grading sheet is included as the final page.	
	50	Laboratory demonstration of your prototype (evaluated by instructor and TAs). Evaluator will manipulate the interface and evaluate how well the system provides the timing and display functions (i.e. how well does the closed loop control work). Is it well built? Neat wiring? (.6 * the prototype evaluation score)	g.2
	15	Rating by reviewers during competition	g.2