Engineering Grand Challenges Capstone Portfolio:

Automating Urban Pollution Clean-Up

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Abstract

The world currently faces many major engineering challenges holding it back from advancing further. One of these major challenges stands out, as it applies less to a grand idea and more to a case by case challenge. This lies in restoring the infrastructure of urban cityscapes in order to allow better progress to be made in those areas. The purpose of the project conducted was to contribute to this grand goal, with multiple different possible angles to tackle it from. The end product and testing was settled to be of an automated robot for trash collection, however. This robot was made in the hopes it would be fully automated, but ended up as research into the field of advanced image processing, to make a product similar to the original goal possible in the future. The results ended with only a 0.645% error between the calculated and real distances. The research conducted through this project was overall a success and can easily be adapted into a future working model of an automated trash collection robot.

Keywords: Engineering, Infrastructure, Automated, Robot

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Engineering Grand Challenges Capstone Portfolio:

Automating the Cleaning of Urban Pollution

Recognize the Problem

Engineering Grand Challenges

The Engineering Grand Challenges are fourteen problems proposed in 2008 by the National Academy of Engineering (NAE), which prove resilient in modern problem solving, improving the quality of life on Earth in the process. These problems allow modern engineers to set goals and find potential solutions to them. The fourteen grand challenges are as follows: Advanced Personal Learning, Making Solar Energy Economical, Enhance Virtual Reality, Reverse-Engineer the Brain, Engineer Better Medicine, Advance Health Informatics, Restore and Improve Urban Infrastructure, Secure Cyberspace, Provide Access to Clean Water, Provide Energy from Fusion, Prevent Nuclear Terror, Manage the Nitrogen Cycle, Develop Carbon Sequestration Methods, and Engineer the Tools of Scientific Discovery (NAE, 2021).

Specific Problem

The problem is restoring urban infrastructure despite ongoing city pollution. This problem can be solved in various ways. Urban pollution is an important problem to solve because it impacts every single person on the Earth; as pollution increases, the air quality decreases and the oceans become more entrenched with dirt. Cleaning and sanitizing the urban environment would restore infrastructure and lessen the environmental impact of pollution.

Potential Impact

Solving urban pollution allows for field innovation and an increased understanding of pollution in the world as a whole. In a global setting, a solution would help provide cleaner cities and infrastructure that would eventually evolve to become a greener population and a cleaner, greener world.

Defining the Problem

Complexities: The problem's complexities revolve around the varying types of pollution and discerning trash from other objects. This is a major challenge as in urban cityscapes there are all types of trash, as well as small, common items that could be mistaken as trash.

Research Questions: What current solutions are being implemented in urban settings? What technologies are currently being developed to aid in this problem? What are some of the biggest challenges those currently attempting to solve this problem are facing? How could we implement our design on a larger scale? What would be a cost-effective plan to construct prototypes?

Goal: An overall decrease in total pollution and an increase in the efficiency of the cleanliness of a specified area would solve the problem. The ideal outcome includes an alternate means of production in case of crisis as well as financial deficiencies. The estimated timeline of the projected outcome is provided in a Gantt chart (*Figure 1*) below.

Figure 1: To see a visualized version of the Gantt chart, click the image below

University of Kentucky **Engineering Design Group Project**

Project Requirements: https://docs.google.com/document/d/10o-Q6

How to Create Video https://youtu.be/ljPcYDqmdIo

Current Date	Days left	Due Date
7-May	4	12-May

	Tasks	Start	Days to Complete	End	Percent Complete	Complete (Info in these columns used for)	Incomplete	Who took the lead on this section?
1	**Problem identification**	8-Feb	4	12-Feb	100%	4	0	N/A
	Background information	8-Feb	1	9-Feb	100%	1	0	Fitzpatrick
	Identify key constraints and variables	9-Feb	1	10-Feb	100%	1	0	Switzer
	Identify success measurement	10-Feb	1	11-Feb	100%	1	0	Marsh
	Complete Gantt Chart Template	11-Feb	1	12-Feb	100%	1	0	Everyone
2	**Research & Conceptualizaton**	12-Feb	6	18-Feb	100%	6	0	
	Mathematical Modeling key component	12-Feb	2	14-Feb	100%	2	0	Fitzpatrick
	Initial drawings of design concepts	14-Feb	2	16-Feb	100%	2	0	Marsh
	Decision Matrix	16-Feb	1	17-Feb	100%	1	0	Everyone
	Choose prototype concept	17-Feb	1	18-Feb	100%	1	0	Everyone
3	**Prototype Synthesis**	18-Feb	31	21-Mar	100%	31	0	
	flowchart	18-Feb	2	20-Feb	100%	2	0	Fitzpatrick
	circuit schematic	20-Feb	2	22-Feb	100%	2	0	Switzer
	3D design	22-Feb	5	27-Feb	100%	5	0	Marsh
	Mechanical build	27-Feb	8	7-Mar	100%	8	0	Marsh
	Electrical Build	7-Mar	3	10-Mar	100%	3	0	Switzer
	Code build	10-Mar	5	15-Mar	100%	5	0	Fitzpatrick
	Test set-up configuation determined	15-Mar	3	18-Mar	100%	3	0	Everyone
	Test for basic function	18-Mar	3	21-Mar	100%	3	0	Everyone
4	**Evaluation**	21-Mar	12	2-Apr	100%	12	0	
	Data collection	21-Mar	5	26-Mar	100%	5	0	Everyone
	Compare data to mathematical model	26-Mar	2	28-Mar	100%	2	0	Everyone
	Normalize / calibrate as needed	28-Mar	2	30-Mar	100%	2	0	Fitzpatrick
	Peer review	30-Mar	1	31-Mar	100%	1	0	Doug Klein
	identify weaknesses/ experiment with alternatives	31-Mar	2	2-Apr	100%	2	0	Everyone
5	**Prototype Synthesis Round 2**	2-Apr	19	21-Apr	100%	19	0	
	update flowchart	2-Apr	2	4-Apr	100%	2	0	Fitzpatrick
	update circuit schematic	4-Apr	2	6-Apr	100%	2	0	Switzer
	update 3D design	6-Apr	4	10-Apr	100%	4	0	Marsh
	update Mechanical build	10-Apr	4	14-Apr	100%	4	0	Marsh
	update Electrical Build	14-Apr	1	15-Apr	100%	1	0	Switzer
	update Code build	15-Apr	3	18-Apr	100%	3	0	Fitzpatrick
	Test new design for basic function	18-Apr	3	21-Apr	100%	3	0	Everyone
6	**Final evaluation**	21-Apr	14	5-May	100%	14	0	
	Gather performance data	21-Apr	5	26-Apr	100%	5	0	Everyone
	Evaluate success rate	26-Apr	2	28-Apr	100%	2	0	Everyone
	Update documentation	28-Apr	5	3-May	100%	5	0	Everyone
	Create video of working design	3-May	2	5-May	100%	2	0	Everyone
7	**Complete Project**	5-May	7	12-May	100%	7	0	
	Create final presentation	5-May	1	6-May	100%	1	0	Everyone
	Practice presenting final project	6-May	1	7-May	100%	1	0	Everyone
	Present final project	7-May	5	12-May	100%	5	0	Everyone

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Research

Existing Solutions

Research was conducted on current methods of urban-pollution-control methods with focus on designs like The City Tree, Baltimore's “Mr. Trashwheel”, and Hydrogen Fuel additive devices. The City Tree and Hydrogen Fuel Additive projects focus on controlling air quality, while Baltimore's “Mr. Trashwheel” focuses on reducing urban pollution in waterways. Initially, research focussed on examining the City Tree’s design and implementation; findings revealed that it is a self-sufficient-stationary replacement for trees in areas where trees could not be grown and offers the same effect as 275 urban trees (Andrews, 2017). It sits at pedestrian level, cleaning the air at an area lower than most trees and targeting areas where the most air pollution is held, while also monitoring environmental and climatic data to ensure the best efficiency of the tree (Andrews, 2017). The City Tree uses moss to filter the air, as this allows for it to efficiently purify the air without requiring filter changes. Along with its use of moss, The City Tree uses solar panels and an integrated water tank to reduce its needed maintenance to only a few hours each year (Andrew, 2017). The City Tree also holds benches on its base (Figure 2), and can have other features added on, additionally providing a lounging place for citizens and a self sustaining solution to urban air pollution. The next topic of research was hydrogen fuel additives which, much like the City Tree, look to reduce air pollution in urban areas. However, it approaches this task in a different way, focusing on a device that uses electrolysis to turn distilled water into hydrogen and oxygen gases. These gases are then injected into the fuel mixture before it's burned to cause a cleaner burn and provide a more efficient and powerful combustion (Hoang & Pham, 2020). These additives decrease fuel emissions due to the increase in efficiency of the fuel causing almost all waste gases to be eliminated (Fleet Industry News, 2017). This provides for normal fossil fuel motors to emit about 80% less harmful emissions when mixed with hydrogen. Next, it was decided to turn to a different form of urban pollution and researched methods used to clean water pollution. For this, research began on Baltimore's "Mr. Trashwheel"(Figure 3), a semi-autonomous remedy to water pollution that uses a stationary, conveyor-belt system placed at a body of water's mouth. The Mr. Trashwheel uses a mix of solar and hydro power along with a combination of solar panels and two water wheels, allowing it to run almost entirely self-efficiently, only needing the collected garbage to be removed and the collection bin to be replaced (Technology, 2019). However, it was found that Mr. Trashwheel's usefulness doesn't end there, as the garbage it collects is taken to a nearby power plant and burned to create electricity. Both processes decrease the waste that flows out to sea and the resources needed to create energy for the city. With this research the next steps of conceptualizing and deciding on a design began.'

Figure 2: The City Tree

Figure 3: Baltimore's Mr. Trashwheel

Conceptualization

New Ideas

When it comes to the cleanliness of urban infrastructure, many approaches can be made. New solutions are few and far between and some are just innovations built from previous working designs, but that is where some of the newer designs come to light. One new idea would be a water filtration system that attaches to the outlets of drainage systems. This would allow for the easily cleanable, replaceable filtration of dirty runoff water that is commonly dumped into nearby bodies of water. The filtration system would consist of two parts, a net to catch large pieces of debris that could potentially clog the system (Figure 4), and the filter itself (Figure 5). To further develop this idea, research was conducted to find methods of natural water filtration and how it works; the research yielded that natural filtration materials such as sand, gravel, activated charcoal, and other rocks are used to clean water as it filters through (Engels, 2019). This is due to sand's ability to absorb bacteria and dirt, while gravel and other rocks can remove large debris (Society For Science, 2017). This research resulted in the developing alternating levels of sand and rock areas to filter water as it flows through. Another solution is a trash collection robot (Figures 6 & 7). Similar to the Disney-created Wall-E, this robot would use a camera built into the robot’s design to scan its surroundings, detect solid pollution, and collect said pollution for removal. The robot would then store the pollution inside of itself and dispense the pollution at a landfill to better centralize the pollution in urban areas (Figure 8). Multiple techniques for the image processing of the bot could be used. Techniques like object recognition, pattern recognition, locating duplicates, image search by fragments, camera’s image processing, and augmented reality (Adoriasoft, 2017) can all be used for simple processing of pollution in the urban environment. However, the primary focus would be on object recognition as we are trying to detect objects from a live video feed. Object recognition is defined as “a computer vision technique that works to identify and locate objects within an image or video. Specifically, object [recognition] draws bounding boxes around these detected objects, which allows us to locate where said objects are in a given scene," (Fritz Labs Incorporated, 2021).

Final Choice Selection

Figure 4: Filtration Net

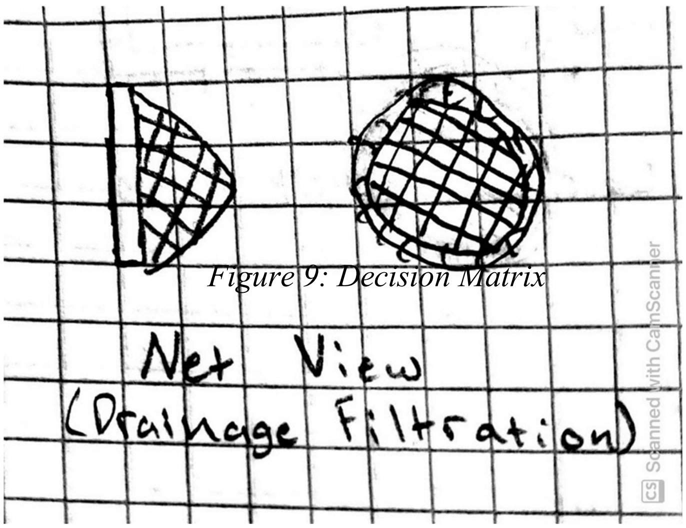


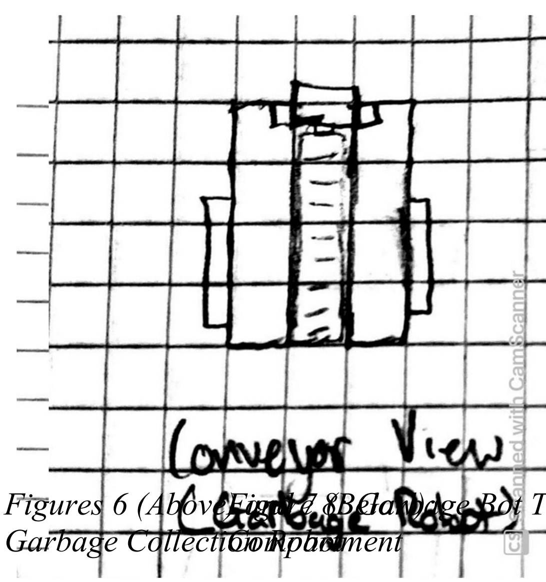
Figure 9: Decision Matrix

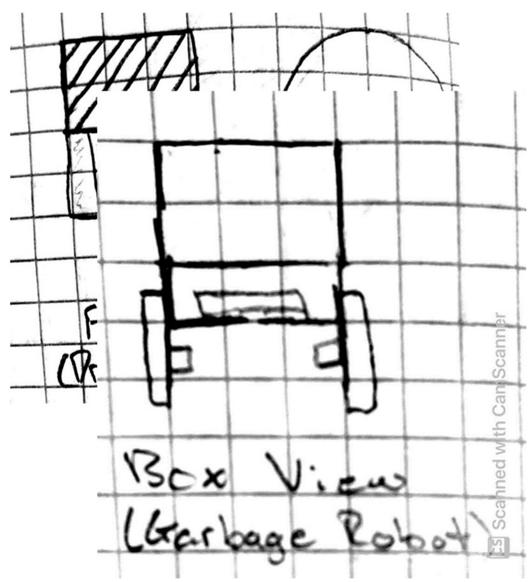
The solution that has progressed to the expansion stage is the automated robot that will guide itself and pick up/collect pollution.

Explanation

The decision matrix was decided based on five criteria, which were chosen based on the future of the project and the team's current ability. Through these criteria, it was found that between a Garbage Collection Robot and a Sewage Drain Filter, the garbage collection robot was overall better. This decision was mostly due to the cost of the sewage drain filters construction and

Figure 5: Filtration





Figures 6 (Above) 7 (Below) Garbage Collection Robot

Figure 8 Garbage Bot Trash Compartment implementation along with the feasibility of the project's implementation. This led to the

	Garbage Collection Robot	Sewage Drain Filter
Cost	3	1
Perceived Effectiveness	2	3
Feasibility	3	2
Size	3	2
Total Points	11	8
Point system based on a score of 1-3 with higher score being favorable		

conclusion that a garbage collection robot was the most cost effective and feasible solution to the problem.

Mathematical Model

The mathematical model decided to visually represent the solution is the conversion factor of pixels to centimeters. Currently, the ratio is one pixel to ten centimeters. This model helps us with the accuracy of our programs.

Prototype Creation

Procedure

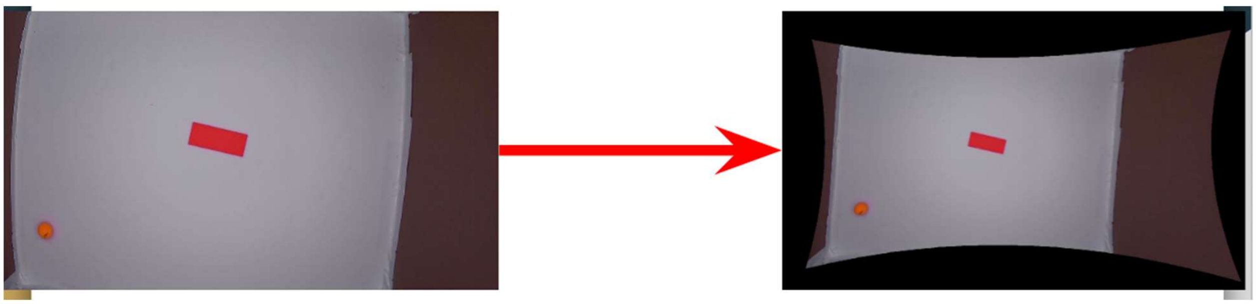
The plan for the prototype is to immediately begin on three different areas of experimentation and working. The first is the construction of the robot itself, being 3D modelled and printed, with multiple pieces being made to be pieced together into a prototype. The next part is starting on the image processing through the matlab integration. The third of those areas is controlling motors to move the robot and to ensure that the communication between the motors and the image processing is working.

Description

Designing a physical prototype and then 3D modelling and printing said prototype was quite a daunting task. The overall design of the robot underwent a large change after initial sketches due to the camera changing and being held overhead rather than on the robot itself. That is in addition to attempting to utilize a much more compact design with the limitations of smaller 3D printers. Over several days, the robot's pieces were being modelled and printed, and during the process, it was discovered that multiple small redesigns were necessary for the structural integrity of the robot, and so the prototyping process took much longer than expected.

With the camera being used to detect pollution in the surrounding area, Matlab can be used via the Computer Vision toolbox. Matlab allows a camera to detect objects and calculate distances from said objects. To do this, a camera is positioned above the designated area and takes a screenshot. Prior to taking the screen shot, the computer has already taken screenshots with checkerboard patterns to nullify the fisheye lens distortion to make sure that the captured image has no kind of distortion on it and that all data collected from the image is accurate (Figure 10). Once the image has been captured, Matlab will continuously process the camera by taking multiple images over and over again inside of a loop structure until the user forces the program to end. Matlab then separates the image into 3 basic layers: a red layer, a green layer, and a blue layer. This allows Matlab to separate the color from the image and decide which layers to use in processing the image. Once all three layers have been binarized and made into black and white images via a specified threshold determined by the RGB values in the layers, Matlab combines the layers into one solid black and white image. The black and white image is shown next to the original image to compare the accuracy of the thresholds. Then, Matlab will locate the white spaces in the image and set up and create bounding boxes, essentially red rectangles, around those white spaces. From there, an algorithm developed independently will execute and take the positions and dimensions of the bounding boxes to calculate the vertical and horizontal distances between these white spaces. When it comes to the prototype, the two white spaces will be a ping pong ball and the robot. Thus, it is effectively calculating the distance between the two objects. Next, it shows the original image with the distances labelled and,

Figure 10, Correcting Fisheye Distortion



finally, outputs the distances to be sent to the Arduino. All of this can be visualized on the next page in Figure 12.

The motors were designed to receive the image data mentioned above, and call programs to turn the motors depending on the nearest ping pong ball's location. The program will acquire information from Matlab and send a basic output to Arduino. This basic output will call a function, telling the motors which way to turn to appropriately collect the ping pong balls. This can be seen below in Figure 11.

Figure 11: Flowchart of Arduino Execution

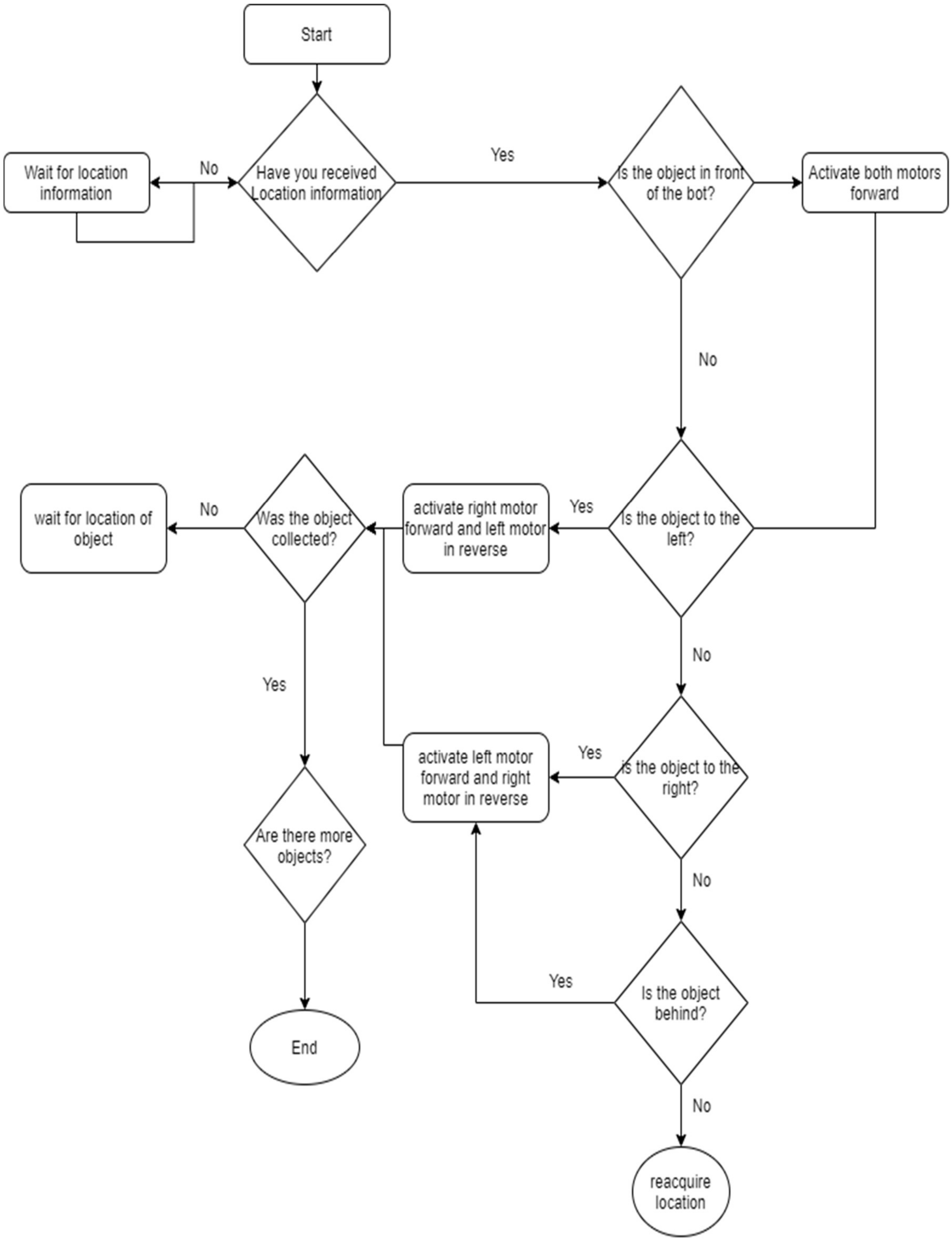
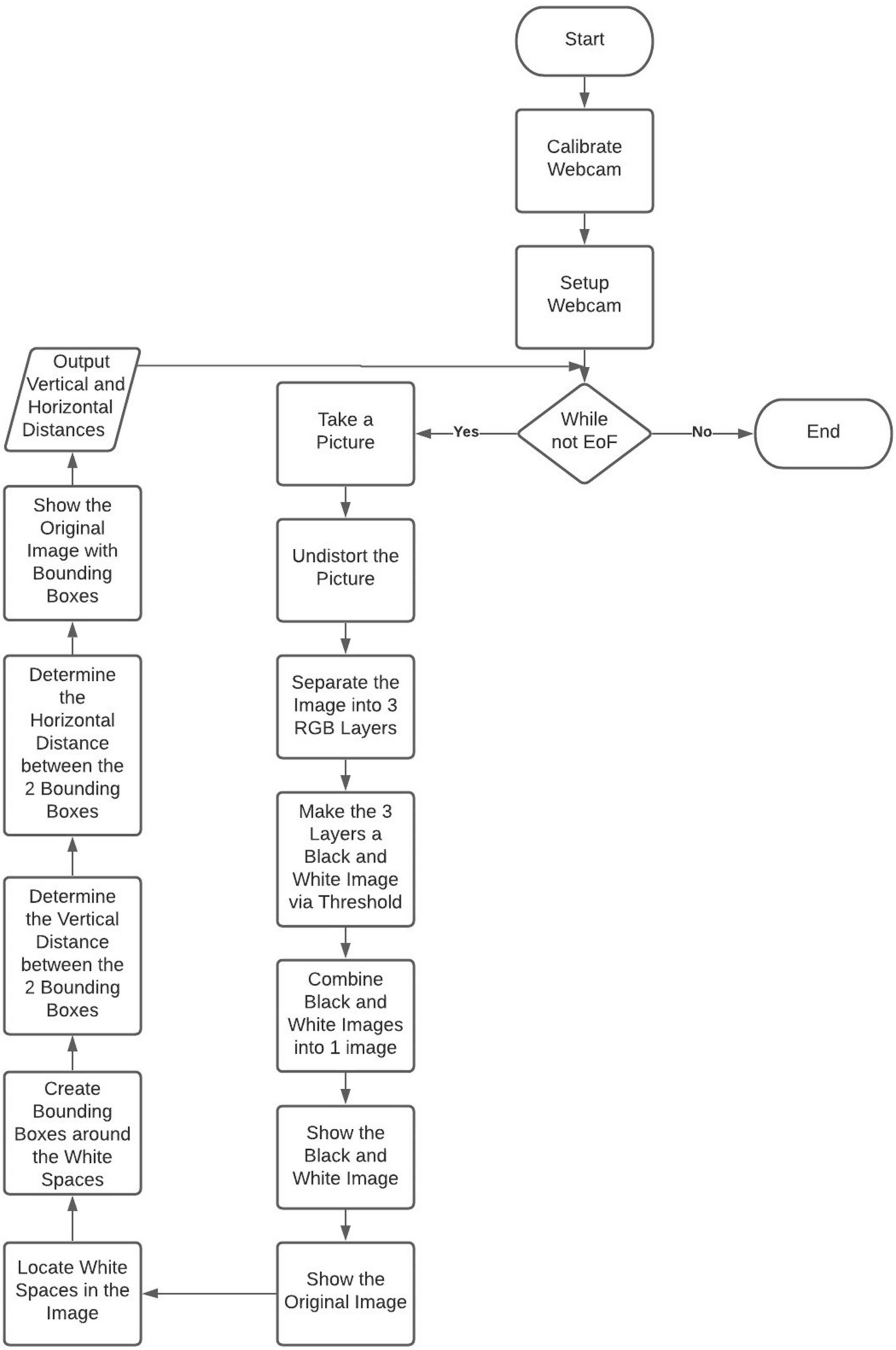


Figure 12: Flowchart of Matlab Execution



Assessment

The difficulties with the physical body of the robot were not only in the constant need for redesigns due to unforeseen issues, but also in the inconsistencies in the equipment being used, namely the 3D printers. Due to their unreliability, they caused multiple delays due to prints not finishing or being botched while only partially completed. The difficulties with the image processing consisted in stabilizing the field to restrict as much outside light as possible interfering with the image processing. Another issue was the skew of the fisheye lens and attempting to calibrate the camera to correct the distortion.

Evaluation and Conclusions

Testing

The prototype designed to test the solution was a field with a trap door that would have the "robot" (the robot used to test the prototype was a 3D printed rectangle made to the same dimensions of the robot) with a ping pong ball inside of it. From this, the Matlab program would calculate the horizontal and vertical distances from the center of the "robot" to the center of the ping pong ball, A.K.A. what represents the trash in this simulation. Next, the actual distance between the ball and robot would be measured by hand and compared to the calculated distances. Afterward, using the Pythagorean theorem, the direct distance of the robot to turn and only move straight toward the ball was calculated and compared to the measured distance.

Data

As seen in Figure 13, thirty data points were collected and calculated using the Matlab program and actual measurements. The "Theoretical X" and "Theoretical Y" distances are the Matlab calculations for horizontal and vertical distances respectively. The "Theoretical Distance" is the calculated distance directly between the center of the robot and the center of the ball. All of the actual distances are measured by hand. Once all the data was collected, the theoretical distance and the actual distances were averaged and then the percent error of the Matlab program was calculated. The result was a 0.645% error which roughly translates to a range of a centimeter through one-fourth of an inch off of the actual distance.

Figure 13: Prototyping Data Spreadsheet

Trial Number	Theoretical X	Actual	Theoretical Y	Actual	Theorertical Distance	Actual
1	30.8	30	36.9	37	48.06506007	47.634
2	41.8	41	26.6	26.5	49.54593828	48.8185
3	10.1	10	22.3	23	24.48060457	25.0799
4	17.9	18	6.3	6.5	18.97630101	19.1377
5	27.9	27	3.4	4	28.10640496	27.2947
6	12.9	13	9.9	10	16.26099628	16.4012
7	0.6	0.5	25.8	26	25.8069758	26.0048
8	41.4	41	17	16.5	44.75444112	44.1956
9	35.9	36	5.2	4	36.27464679	36.2215
10	26.8	27	25.5	26	36.99310747	37.4833
11	27.6	28	32.7	33	42.79077003	43.2782
12	22.8	23	2.5	4	22.93665189	23.3452
13	35.8	36	11.2	10	37.51106503	37.3631
14	29.5	29	19.9	20	35.58454721	35.2278
15	14.8	13	11.5	13	18.74273192	18.3848
16	14.9	16	17.6	17.5	23.06013877	23.7118
17	12.7	11.5	8	9.5	15.00966355	14.9164
18	7.1	8	11.9	12	13.85712813	14.4222
19	27.1	25	13.5	15.5	30.27639344	29.4151
20	16.4	16.5	13.4	12.5	21.17829077	20.7002
21	1.8	1	17.6	18	17.69180601	18.0278
22	21.6	21	2.6	5	21.75591873	21.587
23	19.5	20	19.4	18.5	27.50654468	27.2443
24	10.1	10.5	16.2	15.5	19.09057359	18.7216
25	17.2	16.5	5.3	7	17.99805545	17.9234
26	28.7	26	25.7	24.5	38.52505678	35.7246
27	45.6	45	26	27	52.49152313	52.4786
28	39	41	29.1	29	48.66014797	50.2195
29	25.9	22	25.4	27	36.2763008	34.8281
30	23.6	22	21.8	21.5	32.12786952	30.7612
Averages =	30.0778551	29.89	*All measurements taken in centimeters			
Percent Error =	0.6450561					

Evaluation

The prototyping data, as a whole, would be considered a huge success. With a percent error of 0.645%, the project can assume the next steps with creating a robot that will use the Matlab program to move and collect the ping pong ball. Once this has been accomplished, the final step of field testing can commence. However, there are a few failures in terms of testing. Measuring accurate data for the actual distances was challenging as the testing field is a confined space with little to no room for human movement. There is a possibility that the calculated percent error is slightly skewed to account for the aforementioned human error.

Feedback and Plans for Revision

Over the course of the project, multiple professionals came into the lab to give their opinions on the project's progress. The initial review was while the project was still in the early planning stages, so not many major changes were made. The next time a professional review was provided, the project underwent a large shift. Professor Doug Klein gave insight into the fact that the project was far too ambitious and that the work that had already been done was impressive in its own right. This put the project's final form into view and allowed the project to end in a complete state, rather than being a rushed product.

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