MIDDLE EAST TECHNICAL UNIVERSITY

ELECTRICAL AND ELECTRONICS ENGINEERING

EE 494 FINAL REPORT

SILENTDYNAMICS

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TABLE OF CONTENTS

1. Executive Summary

Throughout the history, the need for transportation has been one of the main concerns of the mankind. Since the realization of the fact that water can carry things, people started to use water channels and rivers for transportation purposes. Even the ancient people have carried their wood blocks using water flow for convenience. Although, water flow is very helpful in carrying a barge, there are many problems that one must face in order to carry the load. To prevent the load from hitting the banks of the canal and make sure the journey of the water vehicle is safe, a driver is needed. Despite the advanced technology that we use in transportation, there is still lack of autonomous drivers for water carriers such as barges. Today we find it very hard to see autonomous machines to carry things along a water canal or a river.

As a newly established company, Silent Dynamics® is very eager to solve this problem for good. 5 encouraged shareholders with different capabilities are filled with enthusiasm to work on a project to make river transportation much easier and autonomous. Company is fully concentrated on an autonomous robot which can carry a barge with its load on a canal, from outside of the canal, collaborating with another robot on the other side of the river. For the barge and the load it will be a very safe and comfortable journey as the robot will prevent them from skidding in the canal or hitting the borders of the canal. The robots will also prevent themselves from getting into the water and stay at a determined distance away from the water. Besides, the robots will be completely stand alone systems so it can be used instead of human based control systems as it will be more time and power efficient and less likely to make mistakes.

As bright senior student engineers they have created many feasible ideas to start with. The main parts of the projects are getting developed day by day. The solution is based on some very cheap sensors, dc motor and drivers. As a result of this the outcome of the project will be very cheap and easily available. The robot will also be quite effective to solve the problem and developable to many advanced systems. Although the robot is to be designed to deal with small loads and a small barge, it may lead so many other projects to carry huge loads or people that may need to be transported over any water stream.

The design and production process of the outcomes of the project, i.e. the autonomous robot itself and the barge to carry on; will be completed in summer of 2017. The first product is planned to be ready to use by the end of May, 2017. In July, it will be available on market with a very reasonable price.

The impact of this project will be very important as it will pave the way for autonomous transportation on water streams. This will make life of so many people easier as it improves the quality of the journey and lowers the cost of it. Considering all of the numerous benefits of the project, this is the project to be supported, encouraged and promoted.

2. Introduction

The demand for automation and smart gadgets is increasing as the technology progresses forward and continues to increase the life standard of people all around the world. Nowadays, a critical part of the workload of the routine operations of humankind is being employed with the help of these machines and systems. Silent Dynamics® is aware of the importance of these systems and the developing technology. Barge Pulling Project is a perfect example of such systems. Working on this project will be a huge milestone for the shareholders of the company and many people will benefit from the prospective product of this project since it brings solution to an important problem.

The robot which is subject to this report will pull a barge along a river with the help of another similar robot. Besides the pulling mission, the robot has two main requirements in order to operate properly. The requirements to complete the curved road while pulling the barge are to keep the barge away from hitting the either sides of the canal and avoiding itself from any contact with the canal side. The design of the robot obeys and satisfies all the rules and conditions that are agreed on the Standard Committee meetings and described clearly in Standards Report.

The design of the robot meets every technical requirement that these requirements bring and uses technological solutions to overcome them. The solution approach consists of three main subsystems which are explained in detail in this report . Briefly, the first subsystem avoids any contact between the canal and the robot by detecting the canal side and making the robot follow the canal at a constant distance even though the forward speed of the robot changes. The first subsystem determines the speed difference between the left and right motors. The second one is the barge detection part which detects the barge and determines the distance between barge and canal. It determines the forward speed of the robot according to the distance between the barge and the near side of the canal. The last subsystem to be introduced as a system which takes the forward speed from the barge detection part and the directions from the first subsystem to drive the motors as desired. Detailed explanation for these subsystems is provided in upcoming sections of this document.

In this final report, one can find any information about the device. The report starts with an executive summary of the project, a detailed description of the overall system. Flow chart and the block diagram about the system are also given besides the technical drawing of the final product. The design specifications and technical descriptions of all subsystems with compatibility analysis are explained in detail. User manual, setup guide and detailed information about the practical use of the robot is also given in the report. Cost, weight and power analysis are also included. Finally the standard compliances are shown under the requirement analysis part.

Silent Dynamics® is very proud to tell the world about the very first product of the company. One can find any information about the system implementation, solution algorithms and the robot itself in this report.

3. Design Description

The design consists of three subsystems; namely barge detection subsystem, canal following (canal detection) subsystem and movement subsystem. Block diagram of the system showing the subsystems and their cooperation can be seen in Figure 1. In our solution, to avoid touching canal edges the robot is following the canal at a determined distance; to prevent the barge touching to the canal side it is changing its speed according to the position of barge's front corner in the canal. A flowchart of the solution algorithm is provided in Figure 2.

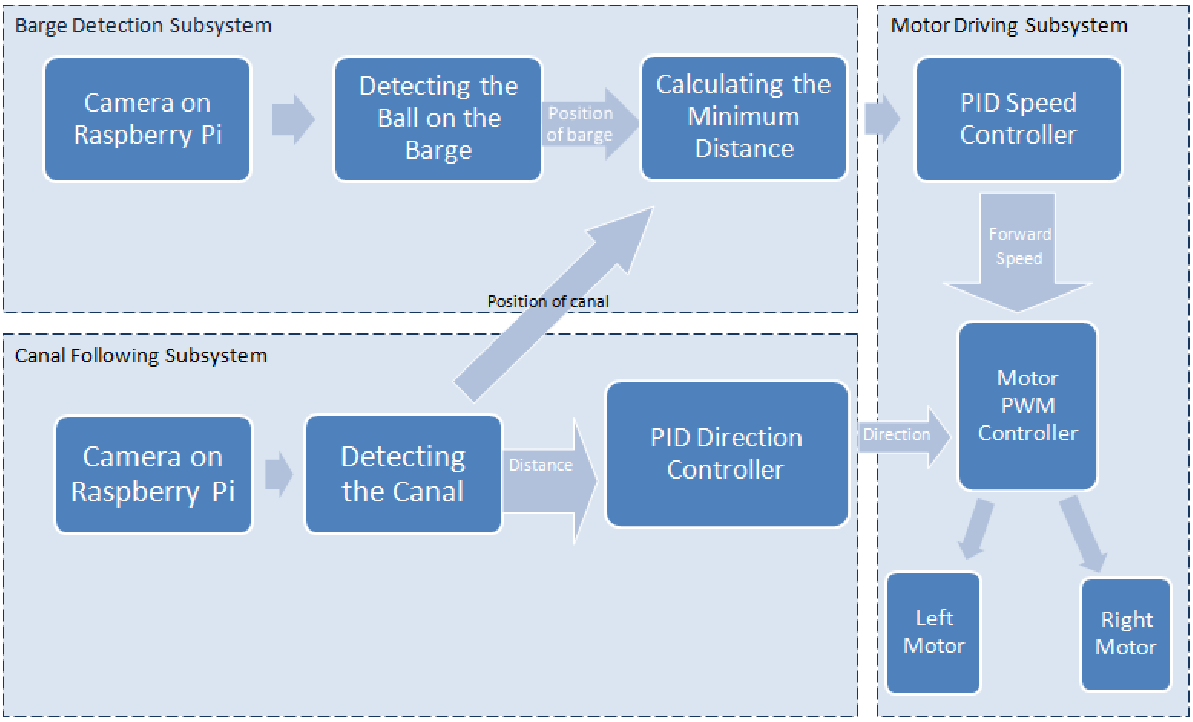

Figure 1. Block diagram of the system

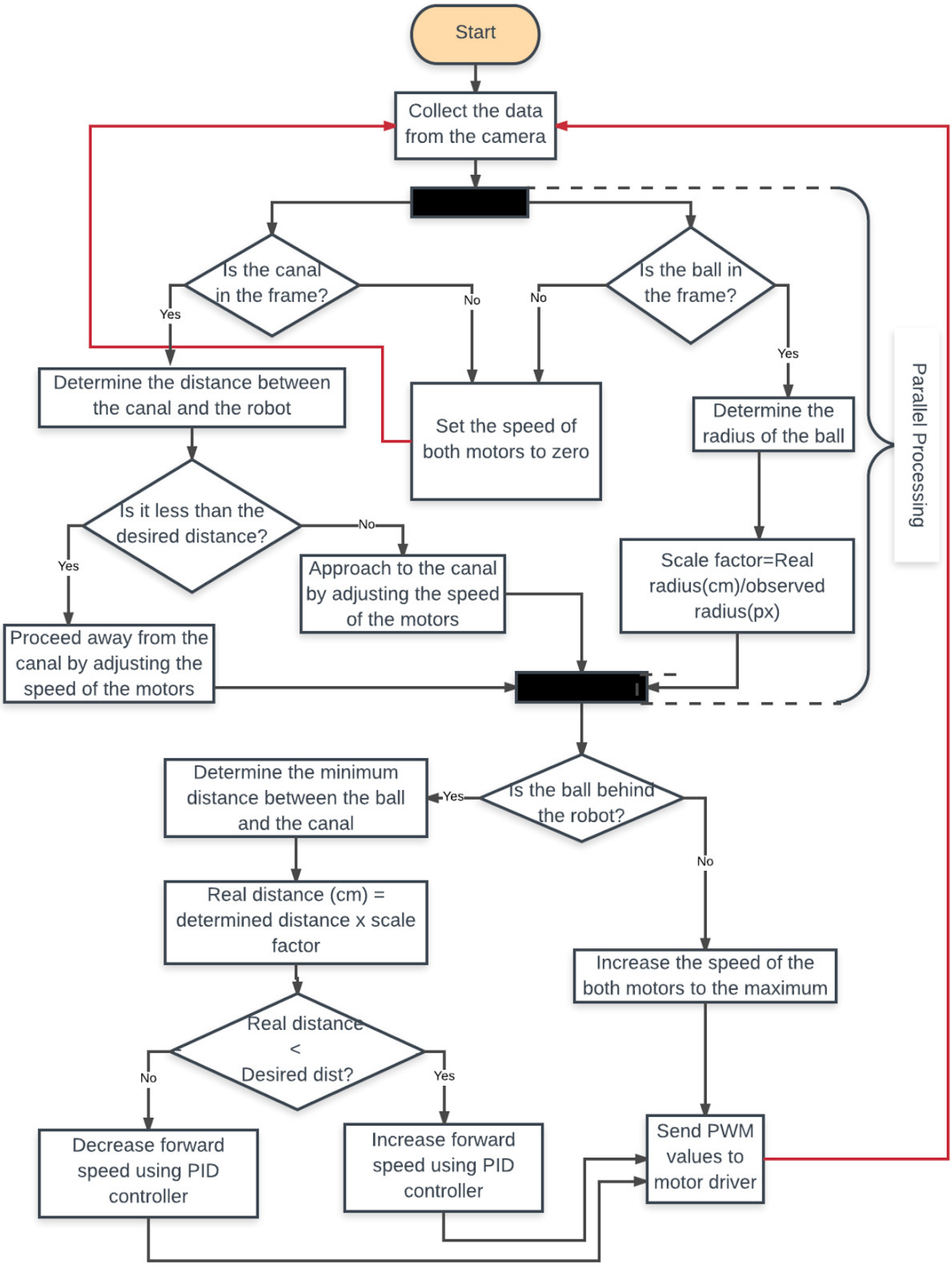

Figure 2. Flow chart of the system

Mechanical Design

Since the number of required elements is few, two small layers (20 cm width & 25 cm height) is enough to place all the necessary components. In order to avoid any possible contact with the canal, a diamond shape layer was selected as chassis.

As the camera holder, a 55cm height "tower" was placed in the center of the chassis. The height was decided by considering the frame of camera vision. Figure 3.a, b and c represents the final design of the robot with its skeleton and the used components on it.

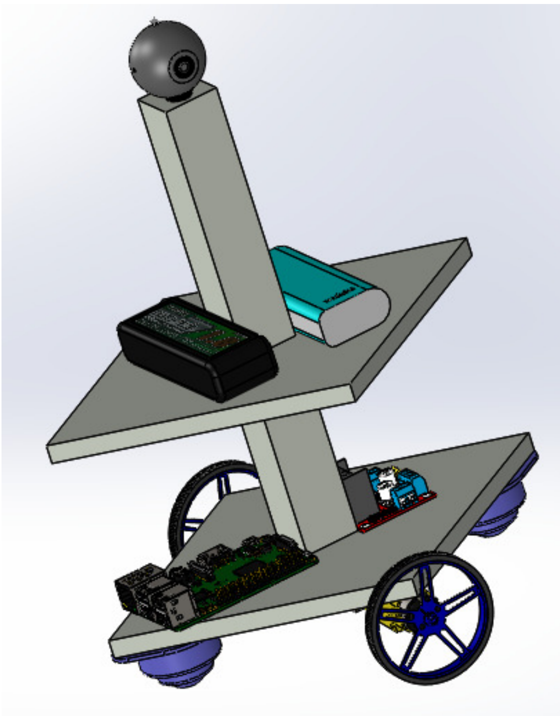

Figure 3.a. 3D drawing of the design

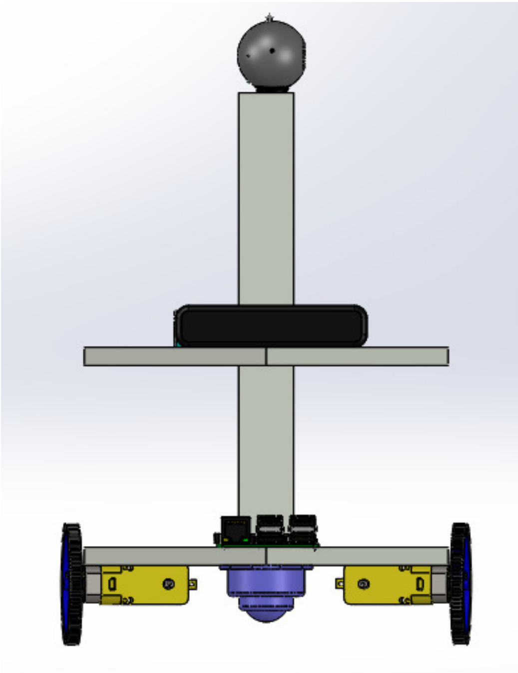

Figure 3.b. Backward view of the design

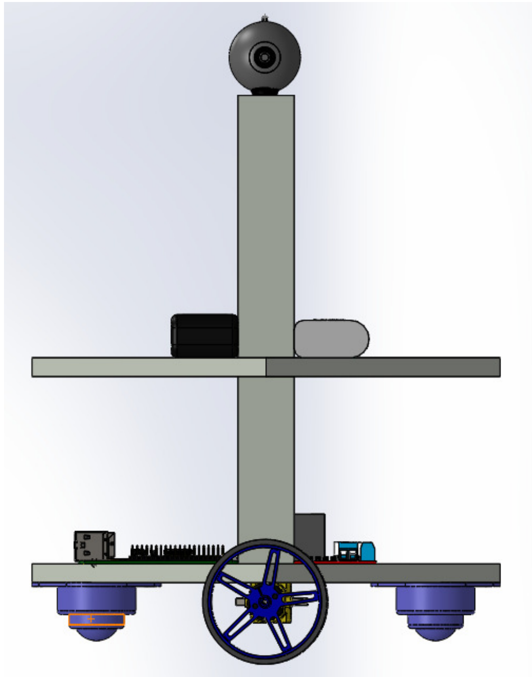

Figure 3.c. Side view of the design

4. Subsystem Description and Tests

4.1 Barge Detection Subsystem

To detect the barge, a 2.0cm-radius ping pong ball is put to the front side of the barge with an adjustable light source (LED) within to eliminate the error arising from different lighting conditions. Figure 4 shows the design of the barge.

There are two advantages of using a spherical object for detection. Firstly, a sphere is a unique object because its projection of any surface results in the same shape: a circle. Secondly, a computer can determine “how much circular” a shape is without using machine learning algorithms with this simple formula:

$$C = \frac{4\pi A}{P^2}$$

where A is area of the shape and P is the perimeter and C is the circularity index of the shape. This value is 1 for a perfect circle and less than 1 for any shape other than a circle.

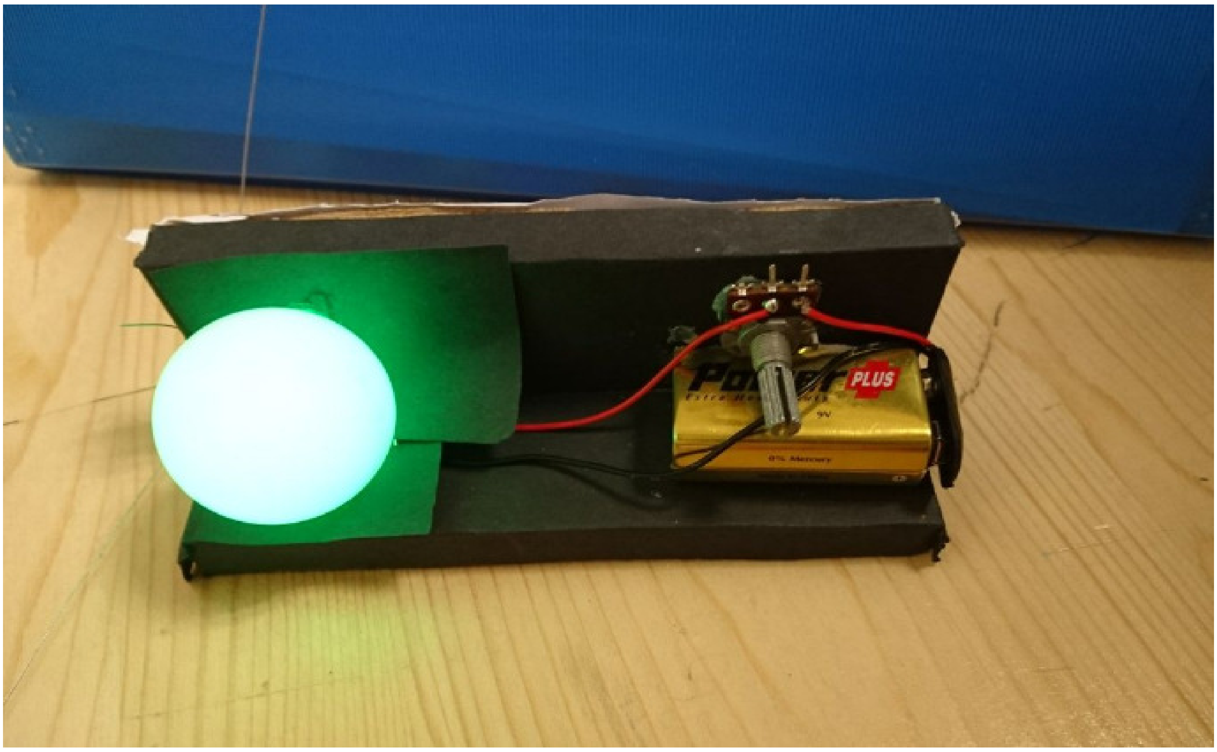

Figure 4. Design of the barge with LED lighting is on.

To detect this ball, the following algorithm is used. Firstly, an image is captured from the camera. Then, it is converted to grayscale and its edges are found with Canny edge detection algorithm[1]. After that, the contours are found from the edges of the original image. Then the contours are eliminated if it does not have following properties.

- Circularity index of the contour must be higher than 0.90.
- Area of the contour is in 20% range of the desired area, which is calibrated after design process.

By eliminating the contours with respect to these features, probability of false detection of the barge is minimized. After the elimination, only 1 contour has left that satisfies these features, unless there is another ping pong ball in the frame, which is extremely unlikely, or there is none. If the resulting number of filtered contours is not 1, the algorithm above is repeated until the number of filtered contours is 1.

After detecting the barge in terms of a contour of the ping pong ball at its front side, the minimum enclosing circle of the contour is obtained in terms of its center point at the frame and its radius in terms of pixels. Then, a scale factor is defined as $\frac{r_{px}}{r_{original}}$ where r_{px} is calculated radius in terms of pixels and $r_{original}$ is the original radius of the ball, which is 2.0 centimeters in our case. This information is to be used for the other subsystems, which are the canal detection and the movement subsystems.

4.2 Canal Detection Subsystem

For the sake of simplicity and low cost, it is decided to detect the canal by the same way the barge is detected: with image processing. To detect the canal with a camera, it is important to design the canal to be easily detected by a camera. Also, the detection must be robust to the errors and computationally easy for a limited-resource computer(Raspberry Pi). For the canal hold these properties, it is designed to be discrete black circles with radii of 0.5 cm printed on discrete square papers with side lengths 2 cm placed on a string. Such design have following advantages. Firstly, it is easy to detect by a camera in terms of edges since each part of it is a black shape on a white surface. By this way, floor color and pattern is eliminated by isolating the shapes to be detected. Also, since it consists of little discrete objects, if an error occurs at detection of an object, its consequences will not be erroneous for the whole subsystem, but only for that particular object of the canal. Moreover, since it is detected as discrete objects (7-8 per frame), it is computationally cheaper than detecting a continuous curve, which consists of countless points. By using this design, computer is saved from excessive computational cost that would be arised from doing calculations with excessively many points each frame. For example, it would calculate the minimum distance from canal to barge with calculating the distance between each point of the canal and the barge. Instead, it only calculates this for 7-8 points for frame. Figure 5 shows the design of the canal.

To detect the canal, the following algorithm is used. Firstly, the contours obtained from the barge detection subsystem are filtered if they do not have the following properties.

- Circularity index of the contour must be higher than 0.85.
- Area of the contour is in 40% range of the desired area, which is calibrated after design process.

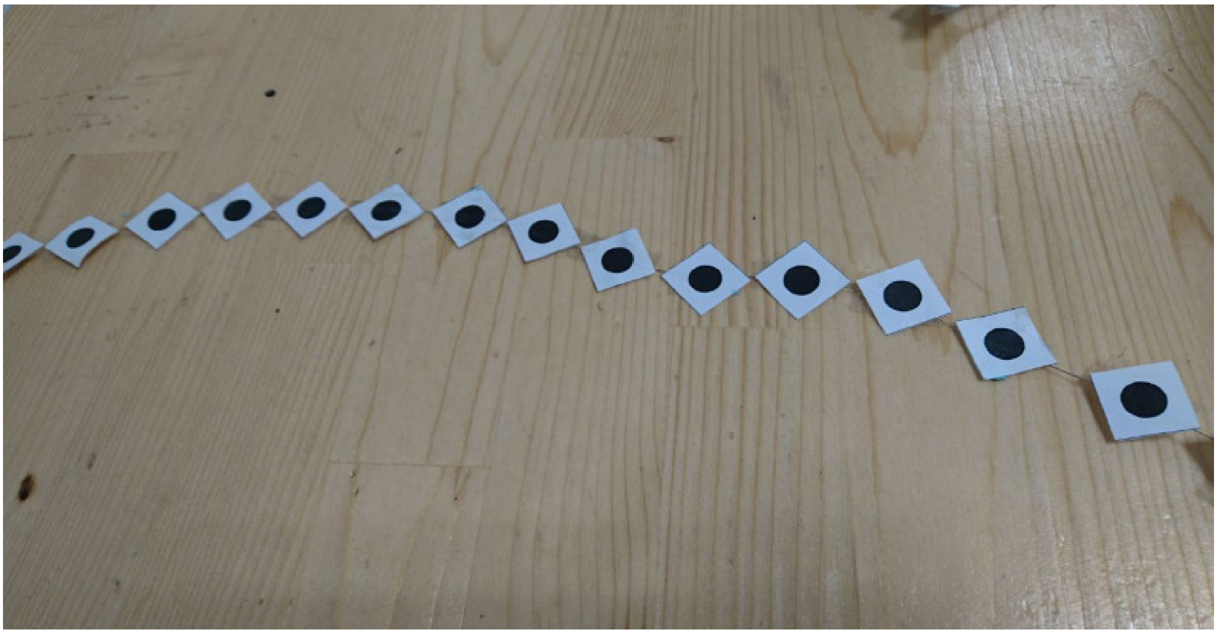

Figure 5. Final design of the canal

Note that the same filtering process is used with different parameters, which also contributes the computational speed and decreases the code complexity. The reason of looser restrictions being set for the filtering this time is that the distance deviation of the canal circles are large and they are not spherical objects, but only circles. That means they are not seen as circles by the camera, but ellipses with lower circularity indexes. The looser parameters being used may sometimes cause some irrelevant points to be detected as canal points since they can sometimes satisfy the filtering properties. However, this is not a problem since the following algorithm is used to filter the irrelevant data: All the detected circles are sorted by x axis value of their center points. Then, the circles having huge deviations in the y axis value of their center points are deleted. By this way, a smooth canal is obtained with no-to-little error. Figure 6 shows the captured camera frame and processed frame with the detected and drawn barge and canal circles. Note that the white circle is the closest circle to the robot amongst the ones ahead of the wheel, which is used to follow the canal with a constant speed.

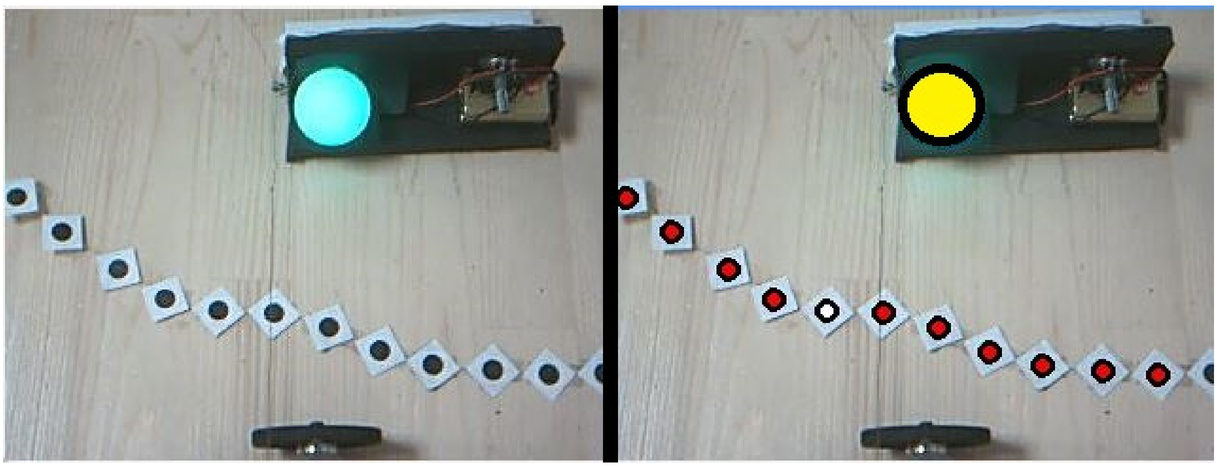

Figure 6. Captured raw frame and processed frame with detected barge and canal circles

For the test of this subsystem, the actual distance between the barge and canal edge is compared with the calculations via the image processing subsystem. Similar to the previous test , 1 cm spaced parallel lines were drawn in the canal as in Figure 7. Ten measurements have been taken starting from one centimeter distance, up to six centimeters distance. The results of the test are provided in Table 1.

Table 1. Results of Test 2

Actual Distance (cm)	Calculated Avg. Distance (cm)	Avg. Error (%)	Standard Deviation (cm)	Min. Measurement (cm)	Max. Measurement (cm)	Duty Cycle Output (%)
6,00	5,98	0,00	0,02	5,95	6,01	44
5,00	5,05	0,01	0,05	4,99	5,11	37
4,00	4,07	0,02	0,01	4,04	4,08	29
3,00	3,10	0,03	0,02	3,07	3,13	22
2,00	2,08	0,04	0,02	2,06	2,10	15
1,00	1,05	0,05	0,01	1,04	1,06	8,5

According to the test results, the proportional controller embedded in the code gives outputs within the range of the error margin that would not cause any troubles under normal conditions of operation. The distance between the barge and the canal side is measured accurately until the near edge of the barge is six centimeters away from canal side. However, for further implementation that would consider the orientation of the barge with regard to the other side of the canal, a wider frame should be used. The height of the robot is adjusted to fifty centimeters while the tests have been done which is ten centimeters less than what it had already been proposed. Therefore, this extra margin of height is used in order to develop the code further for additional reactions and scenarios.

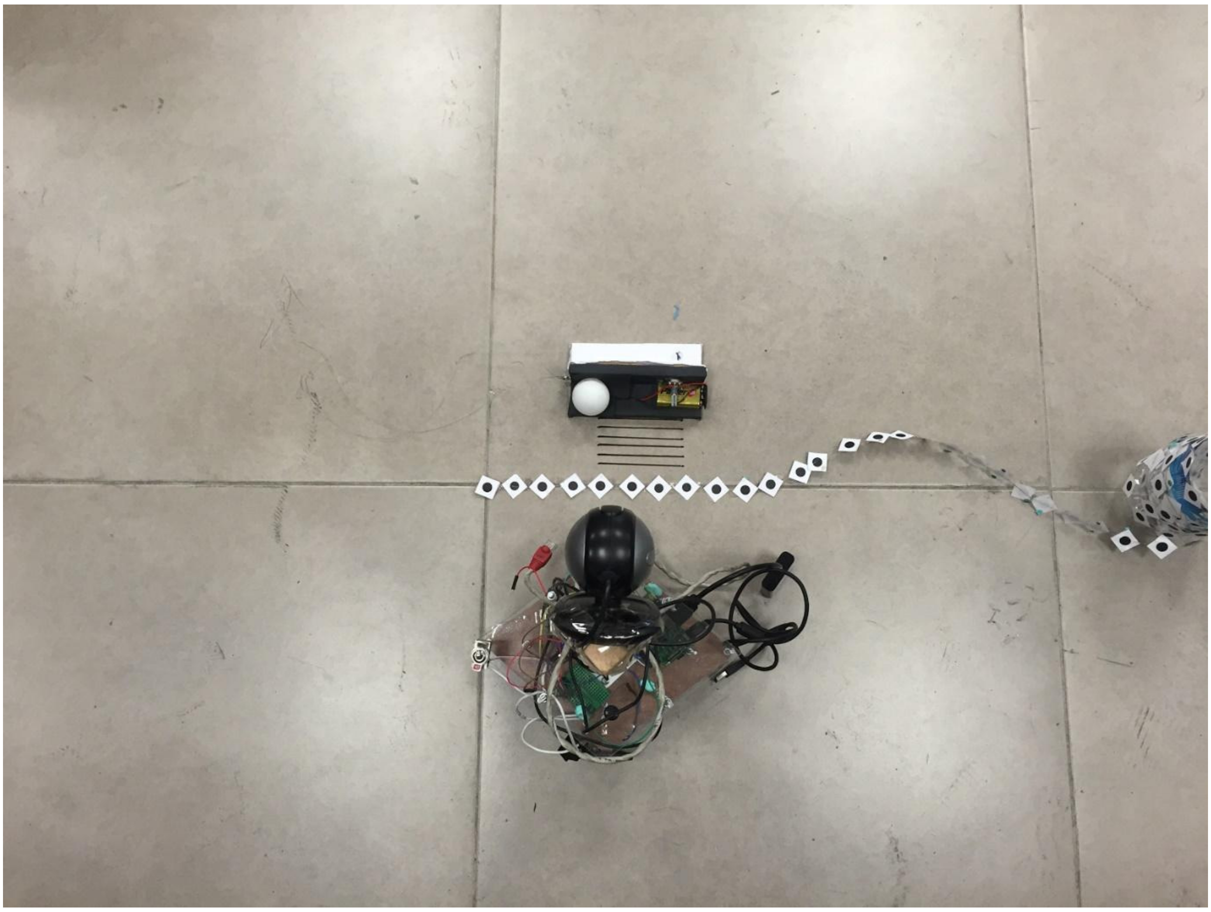

Figure 7. Error estimation test of the barge to canal distance measurement.

Moreover, The test of the movement of the robot under the lighting at METU Cultural and Convention Center (a.k.a. KKM) hall have been done. The robot operates within the predefined error margins and react according to the movements of the opponent successfully under both shady and illuminated conditions. The captions of the camera under both conditions can be found in Figures 8 and 9.

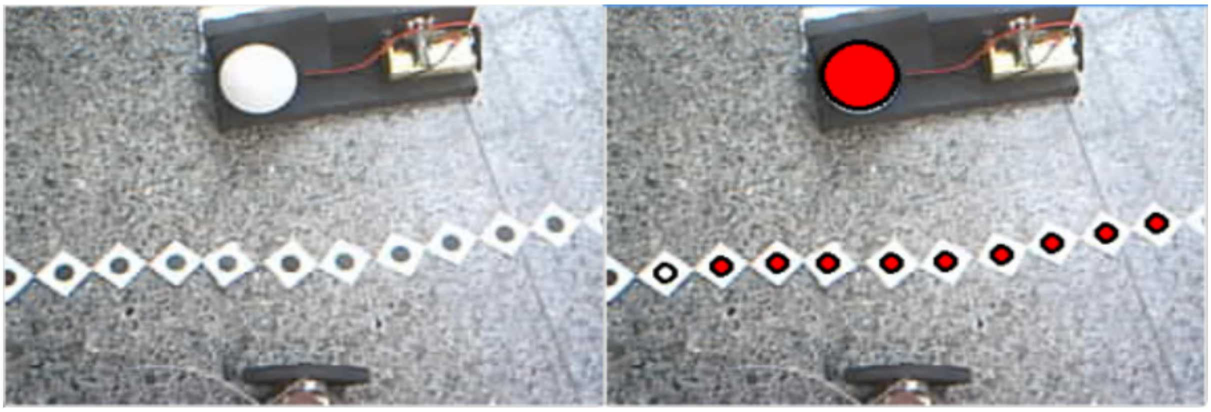

Figure 8. The caption of barge and canal under shade.

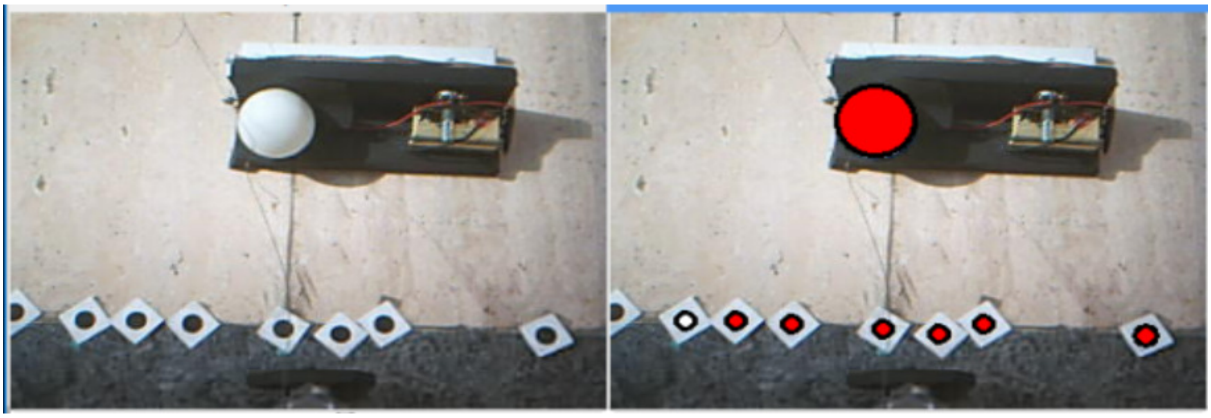

Figure 9. The caption of barge and canal under sunlight.

4.3 Movement Subsystem

After detection of the barge and the canal in terms of circles (center points and radii) and finding the scale factor, calculating the required distances are straightforward.

The minimum distance between canal and the barge is found in terms of pixels by iterating each canal piece first, then it is scaled to centimeters by multiplying the scale factor.

The distance between the canal and the robot is found by the same way. By iteration of each canal piece, the one having the highest y axis value is selected (since the origin is upper left corner). Then, y axis value of the selected circle is subtracted from the highest y value of the image. This result is the minimum distance between canal and the robot in terms of pixels. Scale factor is again used here to convert this value to centimeters.

The distance between the canal and the robot is used to follow the canal with a constant distance. To keep the distance constant, a simple PID controller is implemented. If the distance is larger than desired distance, the wheel further to the canal accelerates while the closer one decelerates over a base speed; if the distance is smaller than desired distance, the wheel further to the canal decelerates while the closer one accelerates over a base speed; thus, the robot follows the canal with a constant speed. However, it is needed to follow the canal with variable speed because the barge is not allowed to touch the canal. Hence, another PID controller is used to adjust the base speed of the robot. When the barge gets further away from the closest canal side, the base speed increases for robot to go faster and pull the barge; and when the barge gets closer, base speed decreases to slow down and stop pulling the barge. Two exceptions for this solution are; if there is no barge (ping pong ball) detected, both motors’ speed is set to zero; when the barge gets ahead the robot, its base speed increases dramatically in order to keep it back to keep the rope tense and provide control over the barge. In this way, the robot follows the canal with a constant distance while keeping the barge inside the canal.

For the parameters of PID for distance adjustment(canal following), we decided not to use Ki since there will be some cases the robot must stop (for example, the barge is very close to the canal). If Ki was set as a nonzero value, integral error would accumulate while the robot is stopped and when it starts moving, the accumulated integral error would cause unpredictable movement. Also, we made our tests with only Kp(Kd=0, Ki=0) for both canal following and base speed adjustment controllers. Since the test results met our success criteria, the tests are considered successful and no further tuning for parameters are made.

The main purpose of the test of this subsystem was to check the error margins along a curved edge as well as along a straight path. Due to the lack of availability of professional equipment, five lines which are 0.5 centimeters apart from each other have been drawn in parallel to the canal side for both the curved and straight paths as in Fig.10. This value chosen is also consistent with the error margins of the camera (the calculated values vs. real distance) that is below 10% which corresponds 0.5 cm for 5 cm following distance.

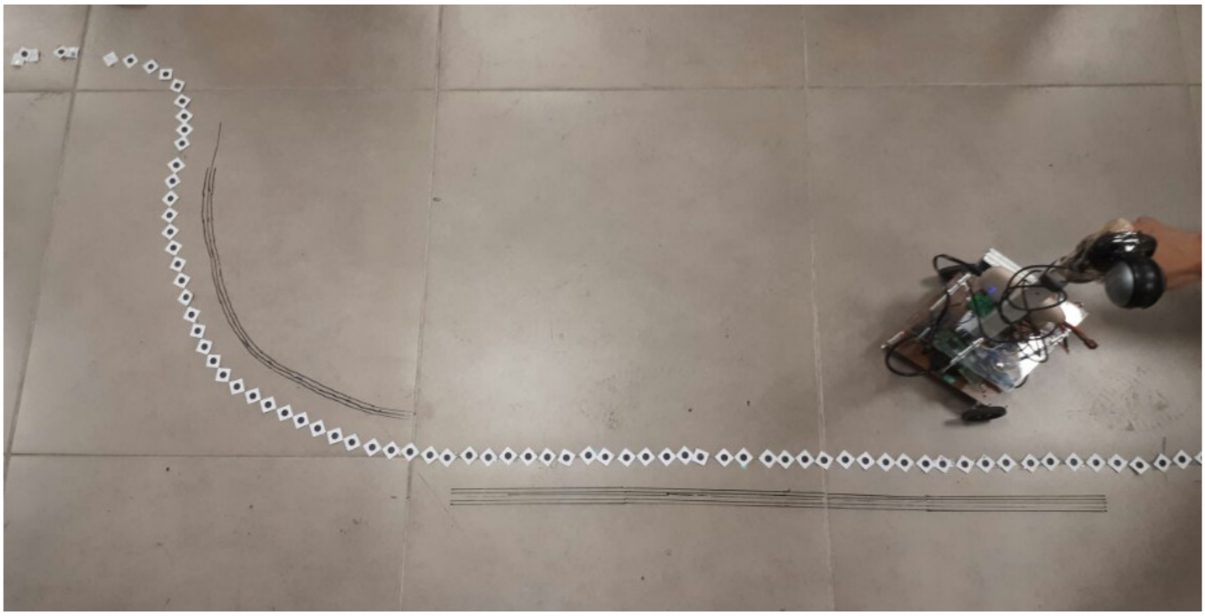

Figure 10. Test design for the errors of canal to robot distance.

Five tryouts have been made each at two different duty cycles that are 20% (average speed of the robot) and 50% (maximum speed of the robot) along the path and each of them has been recorded. The robot did not exceed the 0.5 cm error margin lines for each of the tryouts along the straight path, and for four out of five tryouts along the extreme condition paths in term of curvature. The final test is done with both barge and canal 10 times (5 times to both direction) with the extreme curvature conditions and the neither the robot nor the barge touched the canal while the robot is pulling the barge with Onur(3 times), Esin(3 times) and Ayberk(4 times). After the tests, the robot is considered to be ready for the demonstrations.

5. Weight and Dimension Analysis

5.1. Weight

The final weight analysis table that shows weights of each component to be used on the robot is provided in Table 2.

Table 2: Weight analysis

Expected Weight of the Robot			
Component	Quantity	Weight per Piece (gr)	Total Weight (gr)
DC Motor	2	15.00	30.00
L298N Motor Driver	1	40.00	40.00
Wheel	2	15.00	30.00
Raspberry Pi 3B	1	45.00	45.00
Chassis	1	350.00	350.00
Li-PO Battery & Power Circuit	1	200.00	200.00
Electronic components (resistors, capacitors etc.)	1	30.00	30.00
Cabling and Breadboards	1	200.00	200.00
Total			925 gr

The topic of the weight of the barge was reached to a consensus by each group in Standard's Meeting. The standards state that the bare barge weight is 150 grams and each group has 75 gram of margin for adding extra features for detection. Since our solution on detection of the barge consists of a LED at the front side of the barge, a battery and a potentiometer, the total weight to be put on the barge will be less than 35 grams.

5.2. Dimensions

Previously, while the discussions on the final design of the product were carried on, the dimensions of the robot were decided to not exceed 20 x 20 x 25 centimeters by means of width, length and height. With the shift of point of view on the image processing subsystems used for detection of the barge and the canal side, the camera is decided to be mounted higher and dimensions have been changed. Since there was not any restriction set by the Standards Committee on the topic of dimensions of the robot, these changes will not affect the final product being in compliance. The dimensions of the final design of the product is decided not to exceed 30 x 30 x 60 centimeters by means of width, length and height.

6. Cost Analysis

Silent Dynamics is aware of the fact that bringing a good product to market is not adequate in order to maintain a sustainable business in today's conditions in the markets around the world. Therefore, the pricing of the final product is as important as how it is engineered to have a disruptive product which can shift the market trends when it is launched. That is exactly why some of the components of the subsystems have been got rid of and the product has become much more minimal along the way of development. All of the remaining components of the subsystems are chosen with great efforts and evaluated with respect to several criteria such as performance, cost and durability. Table 3, summarizes the total expenditures of Silent Dynamics throughout the project.

Table 3. Expected Cost Analysis of the Project

Component	Quantity	Price per Piece	Total Price
DC Motor	2	$7	$14
L298N Motor Driver	1	$4	$4
Wheel	2	$4	$8
Raspberry Pi 3B	1	$25	$25
Webcam	1	$7	$7
Chassis	1	$5	$5
Powerbank	1	$10	$10
Li-PO Battery	1	$20	$20
Electronic components (resistors, capacitors etc.)	1	$3	$3
Jumpers and Cables	1	$1	$1
Canal Side	1	$1	$1
Barge Battery	1	$2	$2
Total:			$100

7. Power Consumption

The power consumption of the robot is dependent on the state of operation. The camera mounted on the robot is active all the time, therefore, image processing subsystem which consists of the camera module and the raspberry pi draws power consistently at its base power. Thus, power consumption is directly related to the speed of the motors in use. The minimum power consumption shown in Table 4 corresponds to the motors being inactive and barge being behind and away from the robot, while maximum power corresponds to the barge being in front or very close to the robot ,or, at the curves of the canal side.. In the same manner, average power consumption shows the power consumed when the canal side is straight or the other robot operates at a reasonable pace.

Table 4: Power Consumption

State	Power Consumed (W)
Minimum Speed	2,4
Average Speed	4,5
Maximum Speed	7,2

8. Expected Deliverables

In order to fulfill the customer expectations from the product, Silent Dynamics® will provide necessary documents and tools which can be divided into three different categories, equipment, documents and services.

The Robot

A completely autonomous robot will be provided to the customer by Silent Dynamics®. The robot will be able to carry the barge along the curved path without making it hit the borders of canal and preventing itself from getting into the canal. The robot will also be able to do this given task all by itself, completely autonomous.

The Barge

A barge with the dimensions of 140x40x80mm (wxhxd) with a thickness of 12mm will be provided with the robot. The material used for the barge is appropriate MDF (Medium Density Fibreboard) to fulfill the weight and dimension specifications decided in the Standards Committee.

The Rope

The rope between the barge and the robot produced with appropriate material will be given with the robot. The installation process of the rope on the robot will be explained in Setup Guide.

The Canal Strip

The Canal Strip which highlights the canal borders in order to make it detectable by the robot will also be included in the package. The Strip will be about 2 meters long, containing adjoining circles of 2 cm in diameter. Instructions to use it on any canal side will be described in the Setup Guide.

The Objects to Be Placed on the Barge

A ping pong ball, which has 40 mm diameter, an LED, a potentiometer and a battery will be provided by Silent Dynamics® to be placed on the barge while using the device. These materials will be consolidated to make the installation and to change the direction of the action easier.

User Manual

A booklet to explain the installation of the robot and environment briefly is also provided. The setup process is clearly explained in this manual. The setup guide can be found in appendices with a detailed user manual.

9. Safety Issues and Operational Risks

9.1 Safety Issues

Li-PO Battery

Even though Li-PO batteries are generally safer than other common batteries such as NiCd and NiMH for remotely controlled applications, they still must be handled with care while charging, discharging and storing. Certain risks which might occur and the steps to prevent them are explained below.

- Risk of explosion or fire if overcharged, if subject to physical damage or left in hot environment.
- Reduction of reliability and delamination if subject to high levels of charge is

applied and battery expands

In order to safely use the Li-PO batteries, Li-PO batteries must never be used in environments with high temperatures, always be used with compatible Li-PO battery chargers, and the voltage level of the cells within the battery must always be kept between 3.0 V and 4.2 V. Moreover, the battery should not be left unattended while charging for prevention of cases such as becoming puffy, smoking or even catching fire in order to handle the situation immediately.

<u>Wheels, Hex Nuts and Screws</u>

Two wheels which are connected to two powerful DC motors, various screws and hex nuts are mounted on the product. The product poses risks of jamming body parts or swallowing components to ages below 5. Therefore, it is highly advised that this product is kept away from children’s reach.

<u>Risk of Electrocution</u>

Disassembling the product without properly turning off the power supply could expose the user to electric shock, and possibly injury or death by electrocution. The product must always be kept intact. In case of any physical damage or impact, the product must be inspected by the verified authorities. The product is neither suitable to be used in wet conditions nor in contact with water.

9.2. Operational Risks

There are certain restrictions for the product to operate decently. Some specific scenarios might cause the product not to work properly. These are explained in detail below:

<u>Position of the Camera:</u>

The camera is mounted on top of the product with a specific position and angle. Although it has an error margin to compensate the misusage, mounting the camera without care might cause the robot not to work optimally. Moreover, the detachable stick which carries the camera should be mounted with respect to the canal side that the robot would operate. The canal side should be always inside the frame of the camera.

<u>Canal Side:</u>

The design of the canal side is unique for this robot. It is designed to be very light and simple to use. However, it is crucial for the camera of the robot to follow the black dots on the canal side. Therefore, black dots must never face the floor while the robot operates.

<u>Damage to Environment:</u>

In the case that the camera provides false or no information, there is a risk that the robot may operate unexpectedly which may result in crashing people nearby and damaging the canal side. Therefore, the product should be switched off immediately when this case is observed.

Health Hazards

Risk of explosion or fire if the product is operated for very long durations and if users are unobservant to the Li-PO battery usage safety conditions.

10. Applications of the Product and Impacts on Society

Our product has been designed to operate compliant to the standards of the EE 494 project "Robots collaborating to pull a load along a curved course". Besides its purpose, the solution method to this assignment can be used on possible scenarios. Our design, which is a vehicle capable of avoiding some curved edges while pulling a load, can be used in unmanned vehicles. For example, the image processing and the control algorithm in our design can be adapted to larger autonomous vehicles in factories where they pull the products from one block to another by following the circle-shaped identifiers in front of the shelves. Also, the image processing algorithm can also be thought separately and adapted to smart houses where disabled people live. By processing the vision of camera, possible obstacles such as stairs and corners can be identified by circles and used to warn visually impaired people by voice. Combined with the movement system it can be adapted to wheelchairs as well. The subparts of the design can basically be thought of solutions to line-following and object tracking problems. Hence, by proposing a solution to barge project Silent Dynamics have worked on algorithms and subsystems which can be useful on extensive areas. As company, we believe this design is a solution to fundamental engineering tasks. Hence, applying it to daily life problems may result a widespread use of the product which will make life easier for people.

11. Environmental Effects

One of the issues that must be taken into account while producing an electrical device is its effects to the environment. Being an environment friendly company, Silent Dynamics has designed an environmentally-safe product. Firstly, the robot uses electricity for the power source, so it does not emit any harmful gas as a result of energy usage. Besides, the materials used in the production consist of plexiglass, wood and carton paper which can be recycled. The electrical components can be recycled too. Li-Po battery on the board is rechargeable and it can be thrown into battery disposal cans after it completes its life. While operating, it does not produce any loud noise which could cause sound pollution or be harmful to human ears.

12. Standards Compliance

The Table 5 shows standards to be satisfied and compliance status for a fair competition, which were arranged by the standards committee. By abiding by the rules set by the standards committee, Silent Dynamics holds up to its ethical code, and is in accordance with the Competition Law.

Table 5:Compliance to standards from Standards Committee Final Report

	Standard Item	Compliance Status	Notes
1	Barge Weight	Yes	The barge will be 150 grams. The components to be utilized to detect the barge will not be

			heavier than 75 grams.
2	Barge Movement	Yes	The motion of the barge is restricted in two dimensions meaning that it will be on the floor throughout the carrying process.
3	Barge Selection	Yes	The barge to be utilized will be identical to the ones that are used by other groups.
4	Barge Dimensions	Yes	The dimensions of the barge will have 14 cm of length, 8 cm of width and 5cm of height.
5	Pulling Location	Yes	The barge will be pulled with the help of a hook that is mounted in the

			middle of its front side.
6	Components on the Barge	Yes	The components to be used on the barge will not affect the operation of the other robot. Also, no component that allows communication between the barge and the robot will be used.
7	Barge - Canal Interaction	Yes	Under no circumstances the barge will remain inside the canal and not touch any side of the canal.
8	Pulling Rope	Yes	There will be no restriction by means of the material of the rope to be used.

			The maximum length of the rope will be 60 centimeters.
9	Robot Size	Yes	The robot delivered will not be larger than 20 cm*20 cm*60 cm dimensions.
10	Robot Components	Yes	The robot will be self contained meaning that it will not have any components over the canal or touching the edges of the canal.
11	Battery Restrictions	Yes	The will be no restriction regarding the battery to be used on the robot.

13. Conclusion

This final report was created to inform the interested parties about the final stage of the product. All the subsystems designs and their respective affiliations with the other subsystems are explained in details. By seeing the subsystems as a whole, our final solution to the problem at hand can easily be seen. Also, the total cost of the project and power consumption analysis are performed to see the efficiency of our product in satisfying customer and project constraints. Along these, a list of deliverables is given to articulate what should be expected from the product. Moreover, organizational structure is provided to ensure lucidity , and, information related to the use of the product, risks involved are provided.

To conclude, Silent Dynamics has created the value it aims for, satisfying the project goals that were set. With the final delivery of the product in the demonstration, final design of the barge puller is completed in order to deliver quality and the best possible solution to its customers by fulfilling the project requirements while being competitive and make a significant contribution to the industry.

APPENDICES

A. User Manual

Setup Guide

1- The device will be delivered as one-piece an all installed. Attach the rope which comes out from upper side of the device to the hook which is placed at the front of the barge material. Now you have connected the barge with the robot.

2- Place the canal border line to the corresponding canal side. The canal side will be between the device and the barge. Make sure that all circles on the canal border line is visible and connected each other neatly.

3- The objects to be placed on the barge will also be single-piece in the delivery package. You should place the objects on the appropriate side of the barge according to desired operation direction. The appropriate side of the barge can be found by determining the closer side of the barge to the device when it is moved in the desired direction by pulling the rope for a while in that direction. If you want to change the direction of the operation, simply put the objects to the other side of the barge.

4- For dark places which the light is not enough for the camera to detect the barge, you may light the LED in the ball on the barge by simply connecting the battery to the LED with the small apparatus on the battery. The intensity of light is also adjustable by the potentiometer on the barge.

5- Now the device is installed and ready to use. Now it is time to setup the device on the other side of the canal. If the other side of the canal is already installed, you may start to operate.

How to operate?

WARNING!: Before the operation of the product, it is strongly advised to check the battery levels of the Li-PO battery. Please check the battery after every 1 hour of operation or every 7 days that goes without operation.

1- Make sure that you placed the canal borders properly. After that place the robot facing towards the canal borders from the outside of the canal and place the barge inside the canal between two border lines.

2- There are two switches on the device: The power switch and the direction switch. Before starting to operate, make sure that the power switch is OFF.

3- The direction switch should be directing the desired direction. If not, change the switch position.

4- The objects on the barge should be on the closer side to the device. If not, place them on the other side.

5- Now you have completed the setup of the robot. Turn on the power switch and enjoy yourself while the robot carries the barge along the canal. The robot will do the job all by itself and all you should do is to turn off the power switch after the end of the canal is reached.

REFERENCES

1. Canny, J., A Computational Approach To Edge Detection, IEEE Trans. Pattern Analysis and Machine Intelligence, 1986
2. Chemnitz, M., Schreck, G., & Kruger, J. (2011). Analyzing energy consumption of industrial robots. Etfa2011. doi:10.1109/etfa.2011.6059221
3. https://grabcad.com/
4. http://www.roboweb.net/90-rpm-154-1-20d-metal-dislimotor-pololu-rw-pl-1109.html