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Design and Implementation of an Autonomous Water Surface Cleaning Robot

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Abstract

Water is a vital resource, but industrialization has caused water pollution to become a significant issue. An autonomous water surface-cleaning robot is a machine that is designed to navigate and clean the surface of a body of water without human intervention. The robot is equipped with sensors and algorithms that allow it to detect and remove debris, such as leaves and twigs, from the water's surface. In addition to removing visible debris. one of the main advantages of using an autonomous water surface cleaning robot is the ability to continuously clean the water without the need for human intervention. This allows for a more efficient and effective cleaning process, as the robot can operate around the clock if needed. Additionally, the use of a robot can help to reduce the risk of injury or accidents that may be associated with manual cleaning methods, such as using a net to remove debris. A fixed arm is included for collecting and depositing waste into a basket on the hull, and electronic circuits and motors are protected inside the hull.

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The robot can operate autonomously, including detecting and avoiding obstacles and cleaning the water's surface. It also has a docking station that alerts the robot when it has reached its maximum garbage capacity or when the battery is low. The robot includes modules for movement, positioning, obstacle avoidance, communication, and power management, as well as a system for cleaning the water's surface.
Keywords: Unmanned Systems, Boat, Control loops, Navigation and Control, Robots

1. Introduction

The proposed project aims to design and implement a robot capable of cleaning the water surface of floating garbage in the Nile River. This is necessary due to the negative impact of water pollution on the availability of clean drinking water and the health of aquatic organisms. The current methods, such as semimanual vessels, have limitations in their ability to accurately collect only garbage and avoid causing secondary pollution. The proposed solution is to design a boat with an autonomously controlled system that utilizes a camera, sensors, and object detection system to collect the garbage while minimizing the impact on the environment. The project will involve reviewing and summarizing previous work, developing a preliminary design, conducting motion simulation, and implementing and testing the robot. The goal is to improve the water quality and preserve the aquatic ecosystem of the Nile River.

2. Literature Review on Water Surface Cleaning Robot

2.1. Autonomously Controlled

An intelligent robot system for cleaning plastic trash from the surface of bodies of water is being developed. The robot can detect, track, steer, and collect debris. There are challenges in implementing these capabilities, including accurately and efficiently recognizing garbage, maintaining stability during steering based on vision, and successfully capturing floating debris despite disruptions on the water's surface. The robot is composed of a vision module, motion control module, and grasping module, and can complete three tasks in sequence: cruising and detecting, tracking, and steering, and grasping and collecting. In the first task, the robot navigates a predetermined path on the water's surface and uses its vision module to search for trash. When an object is identified for removal, the second task begins. The vision module tracks the target and calculates the robot's position in relation to it, while the motion control module uses this position data to adjust the yaw angle error for a precise approach angle. The grasping module then determines when to initiate the final task, during which the manipulator grabs and collects the object. The technology is based on an electric underwater vehicle that can travel on the water's surface while carrying a load. The sliding-mode controller approach has been effectively applied as the motion control module due to its insensitivity to model parameters [7].

Recycling the garbage collected by the robot not only helps to clean the water body, but also reduces the carbon footprint of creating new products. Pollutants found in water bodies can be recovered through this process. By removing pollution and monitoring water quality, the robot aims to clean the body of water. While there are several methods for cleaning pollution in the open ocean, there are fewer options for cleaning coastal or rocky water bodies. The robot is effective in cleaning these types of water bodies, especially when large-scale approaches are not feasible. The robot can be used to gather data on pollution and water quality, which can be used to draft local regulations that benefit society. It can be controlled remotely or through an app, and has various features such as automatic cleaning, route planning, edge cleaning, and automatic return. The robot, developed by Ocean Alpha, can identify and avoid obstacles in real-time using millimetres wave radar, lidar, and an intelligent sensing unit. It can also recognize target garbage and adjust its cleaning strategy through ongoing machine learning. The platform can be modified to perform additional tasks such as hydrographic survey, reagent distribution, water quality monitoring, and water plant mowing [3].

The proposed detecting approach allows the capturing robot to effectively clear floating trash in the field. Experimental results show that the modified you only look once v3 (YOLOv3) object detection algorithm performs better than other object identification algorithms in terms of both detection speed and accuracy. This is important for the autonomous and intelligent high-speed recognition and grabbing of moving objects in complex aquatic environments. During clean-up operations, the robot has been able to detect and capture a variety of floating trash such as plastic bottles, plastic bags, and Styrofoam. The YOLOv3 network is used for detection, which is based on the first 52 layers of the DarkNet-53 network and can extract features from images and recognize and classify multi-class objects from 3 scales and 9 ranges [9].

2.2. Remotely Controlled

The design for a waste collection system that effectively removes trash and debris, such as litter, tires, and logs, from rivers, channels, and lakes is part of a larger system. The system utilizes IoT technology to monitor and manage the waste collection process. The vessel, which is designed to remove toxins from waterways and work in areas beyond the shoreline, aims to provide more options for cleaning up the aquatic environment. The river-cleaning robot is made up of three components. The first section deals with the input source, including a mobile phone app with a magnetic switch and a solar panel. The second section focuses on processor development, using Arduino IDE software to code the microcontroller processor with NODEMCU V2. The third section addresses the output source, which combines mechanical components such as DC motors [6].

A motor-driven collecting-arm system has been developed for the efficient removal and redistribution of waste into a rectangular basket on the hull. The prototype's hull is made of Styrofoam and coated in waterproof epoxy, supported by an aluminium wire frame. The propulsion system, based on a differential drive mechanism, provides strong thrust and the ability to turn 360 degrees. Electronic circuitry and motors are installed in the hull to keep them dry, and the robot can be controlled using a remote with Xbee Pro wireless modules. Testing showed that the robot can effectively collect and carry up to 16 kg of rubbish at a time [14].

This study presents a design plan for a water surface collection robot intended for use in deep-sea cage culture. The robot is equipped with a creatively designed forearm drainage and retraction mechanism and has been tested in a prototype and experimental studies on sea surface collection. These studies have demonstrated the viability and rationality of the designed water surface collection robot. The robot is remotely controlled to collect dead fish, which not only improves the efficiency of collecting and cleaning dead fish in the cage culture area but also reduces the workload and potential safety risks for the cage culture crew. The experimental results show that the robot is a simple and effective method for collecting and cleaning dead fish on the water's surface in the deep and open sea cage culture region, offering a better accuracy trade-off compared to other marine waste collecting techniques [10].

According to a different approach, the bot will search for waste patches along the road and collect the rubbish, clearing the waterways in the process. In this method, if someone is found poisoning the water sources, a monitoring system alerts the authorities. A more sustainable system has been made using solar energy. The use of computer vision algorithms allows for the detection of trash on the water's surface. This trash is collected by the bot, who then dumps it in a designated location. In addition to cleaning the water bodies, preventive measures like virtual fencing have been utilized to alert the authorities if someone tries to contaminate the water premises. The movement of the bot and shore surveillance are both monitored by web applications and mobile apps, respectively. Both preventive and curative steps are included in this comprehensive solution for water maintenance. The surveillance system will activate a camera at the shore to look for anyone attempting to contaminate the waterways by employing image processing methods. Image processing algorithms are used for person detection. Based on the discovery, an alarm will be sent via the app to the authorities so they can take the appropriate action. Using deep learning and OpenCV models, the image processing technique is utilized to recognize human activity along the coast and classify it as either polluting or not polluting water bodies. To use the app to access the live video feed produced by the cameras (both the one mounted on the boat and the one used for offshore monitoring); they use the custom TCP tunnel service offered by Remote.it. Remote. it establishes a tunnel connection between TCP port 8081 of the Raspberry Pi (which runs motion) and the end device which allows the video stream to be accessed remotely [2].

3. Simulation

3.1. Vehicle Dynamic Model

The behaviour of ships can be explained by utilizing highly nonlinear equations based on Newton's second law (Gierusz,2016).

$$m(u + qw - rv) = X_{tot} \quad \text{Eq. (1)}$$

$$m(v + ru - pw) = Y_{tot} \quad \text{Eq. (2)}$$

$$m(w + pv - qu) = Z_{tot} \quad \text{Eq. (3)}$$

$$Ixp + (Iz - Iy)qr = K_{tot}$$ Eq. (4)

$$Iyq + (Ix - Iz)rp = M_{tot}$$ Eq. (5)

$$Izr + (Iy - Ix)pq = N_{tot}$$ Eq. (6)

where:

The mass of the ship is represented by m, while the moments of inertia around X, Y, and Z axes are represented by I_x, I_y, and I_z respectively. The total forces acting along the X, Y, and Z axes are represented by X_{tot}, Y_{tot}, and Z_{tot}, respectively. The total moments acting on the hull are represented by K_{tot}, M_{tot}, and N_{tot}.

In many control scenarios such as stabilization of heading, speed, and trajectory, it is typical to disregard the pitch, roll and heave motion by assuming that p = q = w = 0. This simplifies the 6-degree of freedom model of the ship to a 3-degree of freedom model as shown in Fig.1.

$$m(u - rv) = X_{\text{tot}} \quad [\text{N}]$$ Eq. (7)

$$m(v + ru) = Y_{\text{tot}} \quad [\text{N}]$$ Eq. (8)

$$Izr = N_{\text{tot}} \quad [\text{Nm}]$$ Eq. (9)

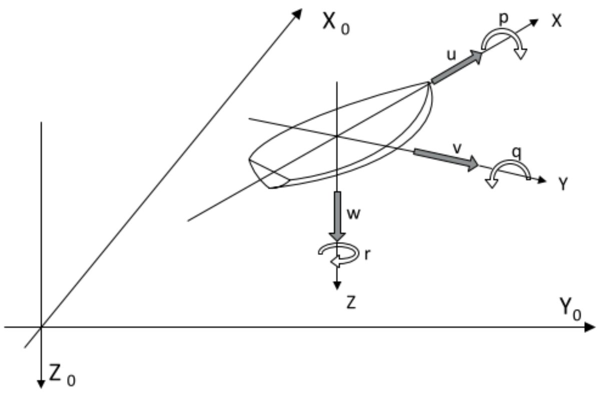

Fig. 1 the Earth-fixed reference frame X0-Y0-Z0 and the ship-fixed.
(Gierusz,2016)

3.2. Vehicle Dynamic Model Simulation

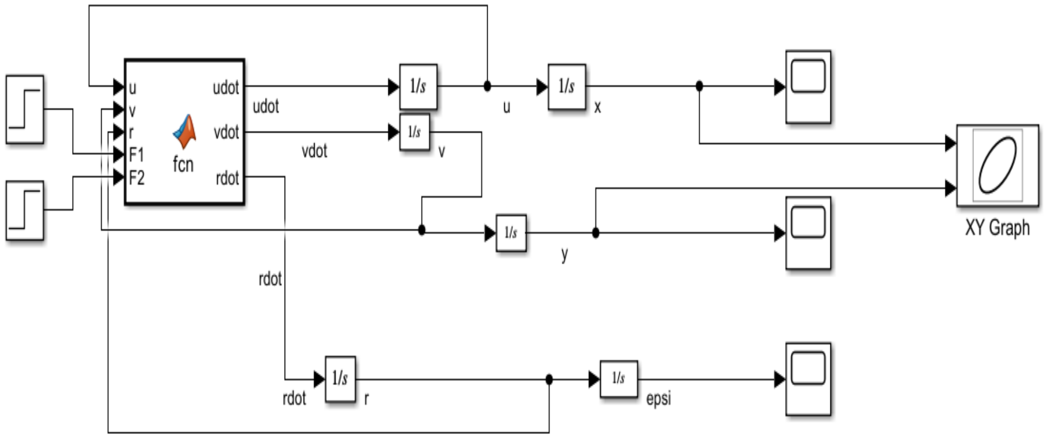

Fig. 2 Dynamic Model Simulation

The vehicle dynamic is implemented on MATLAB/Simulink as mentioned in Fig.2 above. The two input forces are F1 which is a force acting from one of the propellers and F2 acting from another propeller.

4. Hardware design

After studying the environment in which the robot will operate, the proposed autonomous system will face various challenges. For example, the Nile River is a dynamic environment that is subject to fluctuating water levels and currents. The robot will need to be able to navigate these changing conditions while maintaining its stability and collecting the garbage. Additionally, the robot will need to be able to withstand the harsh weather conditions in the Nile River, such as high temperatures and intense sunlight. Furthermore, the robot will need to be able to detect and collect a variety of different types of garbage, including plastics and other debris that may be floating on the water's surface.

However, the project also has several constraints that must be taken into consideration. First, the robot must be safely isolated to avoid short circuits and preserve its components from water. Second, the robot speed is capped at 0.7 m/s to ensure its stability and safety. Third, the batteries should help the robot to work for more than 2 hours to make sure that the robot does not as well as make sure that the robot can reach its recharging destination safely. Fourth, the total voltage supplied to the robot is 12 V. Fifth, the communication range is 2m Obstacle Avoidance. Sixth, the single cleaning capacity is 8 kg. Lastly, the robot Material is PVC.

Overall, the environment in which the robot will operate is complex and challenging, but with the appropriate design and technology, it has the potential to be a powerful tool for cleaning the Nile River and preserving the aquatic ecosystem while considering the project constraints.

After studying the environment in which the robot will operate and taking all the constraints into consideration, we have developed a 3D CAD model of the robot using CAD software as shown in Fig.3.

Table 1.

"Robot Specifications"

Design parameter	Value
Dimensions (overall)	80x60x40cm
Net weight (only robot)	40kg
Maximum weight (with load)	48kg
Average battery while cleaning	2 hours
Propeller type	three blades
Control system	Autonomous

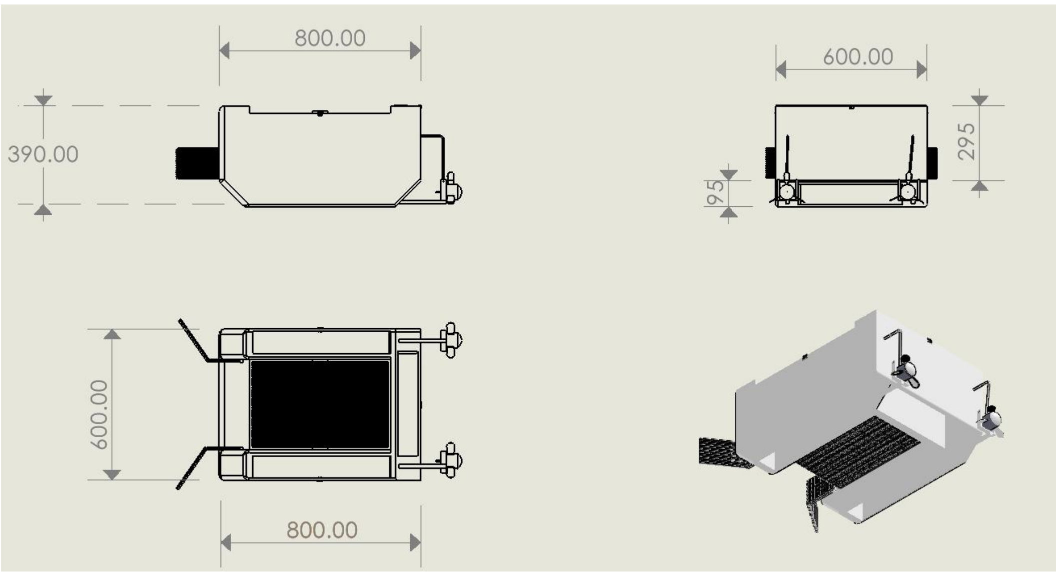

Fig. 3 Robot design(mm)

The proposed robot design incorporates various components to deliver its functionality, including actuators, sensors, and additional crucial elements. The actuators of the robot include brushless DC motors, which provide a high-efficiency and reliable means of propulsion. The brushless DC motor is known for its high efficiency and precision which is crucial for the robot to navigate in the dynamic conditions of the Nile River.

Sensors play a crucial role in the robot's ability to navigate and collect garbage. The robot is equipped with an IMU (Inertial Measurement Unit) sensor which provides information about the robot's orientation and motion. This sensor is crucial for the robot to maintain its stability and navigate the changing conditions of the Nile River.

Additional crucial elements include a GPS module, which provides the robot with its location and allows it to navigate to specific areas of the Nile River. The robot is also equipped with a Li-ion battery, which provides a reliable power source and ensures that the robot can operate for more than 2 hours. Additionally, the robot is equipped with a Raspberry pi Camera module, which allows the robot to detect and collect garbage and a relay module that helps the robot to avoid obstacles. All these components are integrated to work together as shown in Fig.4 to deliver the robot's functionality and achieve its goal of cleaning the Nile River and preserving the aquatic ecosystem.

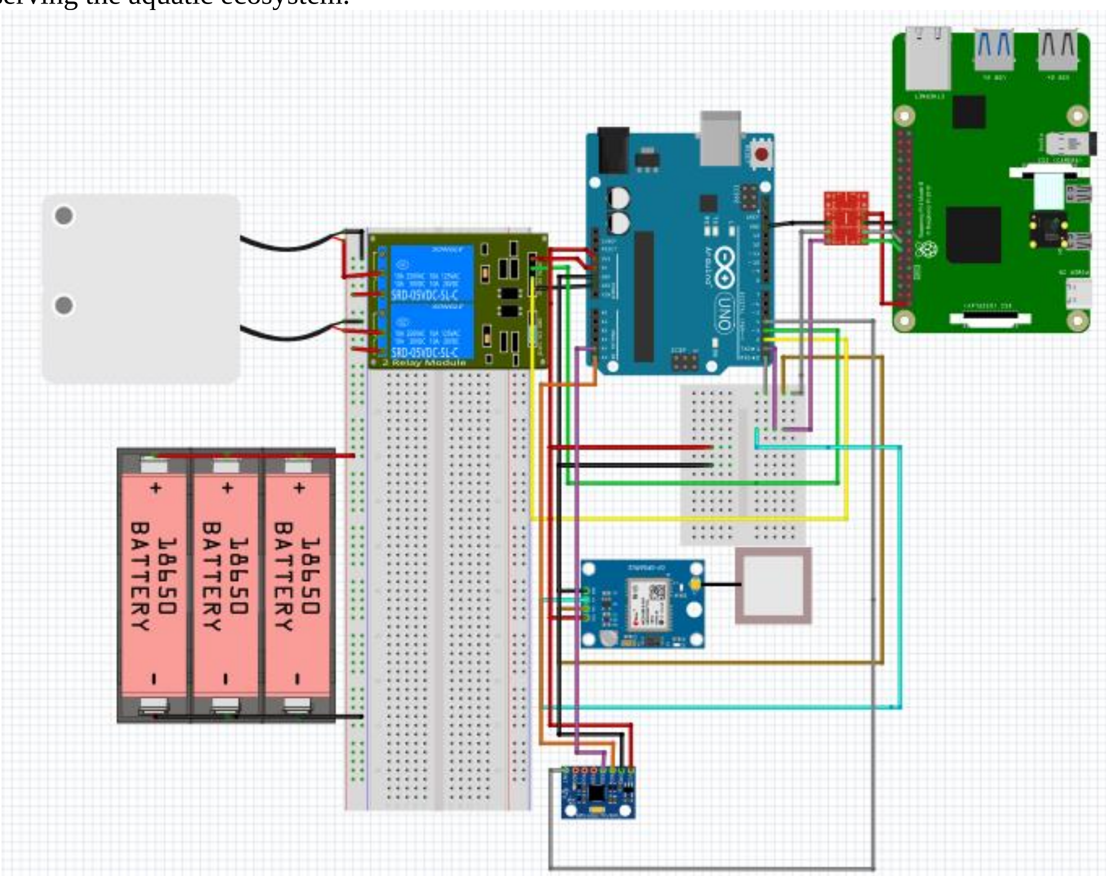

Fig. 4 circuit design

The nature of the environment where the robot will operate. Also, the robot CAD model with their dimensions and this done using 3D CAD tools to draw the robot and simulate it, as well as a detailed examination of the process for selecting motors for the robot and comparing them to other options. The work environment and its characteristics were examined thoroughly, then the selection criteria for the appropriate motors were discussed and different types of motors were evaluated and compared. Also showing the criteria of selecting the appropriate microcontroller, sensor, and other essential components and showing the component's wiring diagram.

5. Results

The simulation conducted in MATLAB provides insight into the dynamics and performance of a particular system under various conditions. The results show the system's behaviour and performance under different scenarios.

5.1. General case

The robot's speed is moving in a straight line, as indicated by the absence of motion in the Y direction and the Fig.5 shows that there are no steering angles present in this case.

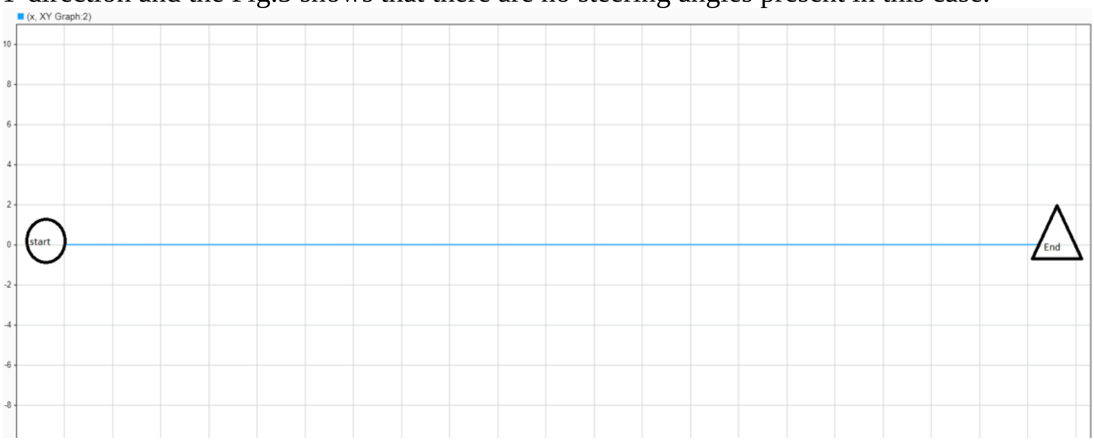

Fig.5 General case on XY graph

5.2. First Case

The results of the first case show the situation when the speed of motor two is increased with respect to motor one, the robot initiates movement in an anti-clockwise direction. This movement continues until the robot reaches the necessary angle to effectively collect the garbage as identified by the camera. In addition, the Fig.6 below represents the X Y graph which describes the critical movement of the robot with this steering angle.

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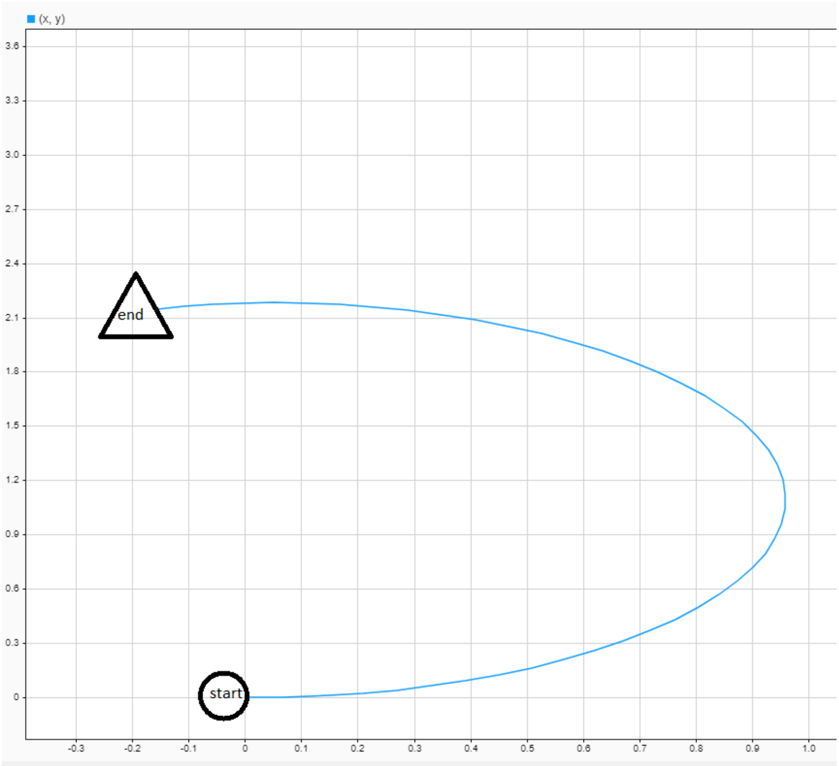

Fig.6 First case on XY graph

5.3. Second case

In the second case, when changing the speed of motor two less than motor one. The robot starts moving clockwise until reaches the required angle to collect the garbage that was captured by the camera. In addition, the Fig.7 below represents the X Y graph which describes the critical movement of the robot with this steering angle which indicate that as the speed of the robot changes than the first case the robot will rotate in the opposite direction of the first case.

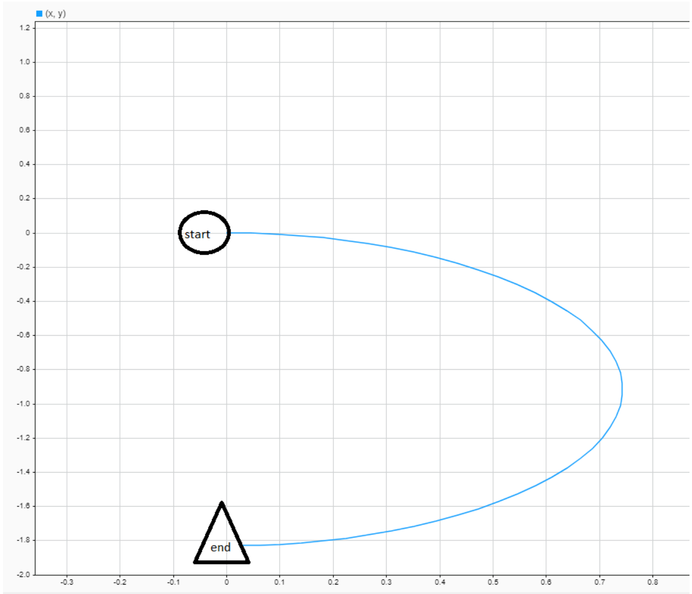

Fig.7 Second case on XY graph

6. Prototyping

To prove the concept of design we have manufactured a scaled prototype as shown in fig.8 to verify the concept**.**

Fig.8 Prototype

7. Conclusion

In conclusion, the project presents the design and implementation of an autonomous water surface-cleaning robot that can collect floating garbage from water surfaces. The robot's design ensures stability, navigation, and payload capacity, making it an efficient tool for cleaning the Nile River and preserving the aquatic ecosystem. Additionally, the robot uses changes in motor speeds to navigate and collect garbage efficiently. It adjusts its movement in response to the presence of garbage and the required steering angle, as observed in figures, effectively navigating, and collecting garbage.

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