Autonomous Vessel Design for Efficient Marine Debris Collection: A MATLAB Simulink and Arduino-Based Approach

Qinze Kong

Abstract.

The growing threat that marine pollution poses to human health and biodiversity requires innovative responses. This study aims to create autonomous, unmanned vessels for collecting marine debris to prevent the negative effects of marine litter, especially plastics and industrial waste. The study uses MATLAB Simulink for dynamic modeling, simulating how the ship interacts with different debris and maritime settings. The effectiveness of advanced control systems that combine feedforward and feedback controls is evaluated regarding debris collection and pathfinding. The methodology of this study involves the design and simulation of the vessel's hydrodynamic behavior, control systems, and debris interaction mechanisms. A scaled-down prototype has been built, integrating elements like a double-propeller hull, Arduino-driven control mechanisms, and a debris-gathering system. The prototype's efficiency in gathering debris and mobility is demonstrated by real-world testing conducted in controlled situations. According to the results, the integration of modern control systems has been found to greatly improve the vessel's debris collection efficiency. How the prototype functions in different situations demonstrates its ability to serve as a scalable solution for marine pollution. The result of this study emphasizes the possibility of automated, unmanned marine debris collection vessels as an environmentally friendly way to reduce marine pollution. The effective prototype testing, modeling, and simulation bring up new avenues for research and development in this area, which benefits the preservation of marine ecosystems.

Keywords: Marine pollution; Marine debris collection; autonomous vessels; vessel routing problem; control systems.

1. Introduction

With serious risks to human health, biodiversity, and marine ecosystems, the problem of marine pollution has grown into a global emergency in recent years. Large volumes of trash have accumulated in our oceans due to industrial discharges, insufficient waste treatment systems, and an exponential increase in plastic manufacture[1]. Pollution affects almost all marine organisms [2]. In the face of marine pollution, marine debris collection vessels have emerged. These specialized vessels are designed to respond to the need to clean oceans, rivers, and lakes and are an effective way to mitigate marine pollution. Equipped with advanced collection devices and navigation systems, these vessels range from large, manned vessels capable of cleaning up vast ocean areas to small, short-range vessels adept at navigating narrow waterways. As these technologies evolved, it became clear that existing vessel designs had a bottleneck. They do not provide immediate relief from the growing water pollution problem, and this paper takes an in-depth look at a new type of unmanned automated marine debris collection vessel [3]. Modeling ships and marine debris using MATLAB Simulink is utilized to test and plan automated courses of action for ships. Different control methods are applied to evaluate the vessel's efficiency of automated marine debris collection. The goal, following testing, is to enable automated pathfinding and the vessel's return to a predefined position. After completing the simulation phase, a small-scale prototype of the new unmanned marine debris collection vessel is designed, incorporating both the hull and control system. This research aims to create advanced, autonomous, unmanned marine debris collection vessels to greatly reduce the growing issue of marine pollution. By innovating in this field to address the pressing problems of biodiversity loss and ecosystem damage brought on by marine garbage, especially plastic debris [4]. In the end, this effort helps to achieve the more general objectives of protecting the various species that live in these seas, maintaining the health of maritime ecosystems, and maintaining marine environments. In addition to supporting environmental conservation, this project promotes sustainable management of marine resources, which is essential for the next generation.

2. Modeling in Matlab

Simulink provides a platform for dynamic modeling of the ship, considering factors like buoyancy, resistance, propulsion, and environmental forces. This comprehensive approach is crucial for predicting real-world behavior and performance [5]. Accurately simulating the hydrodynamic environment is key. This includes modeling water flow, wave patterns, and their interactions with the ship and the floating objects, as Figure 1 shows.

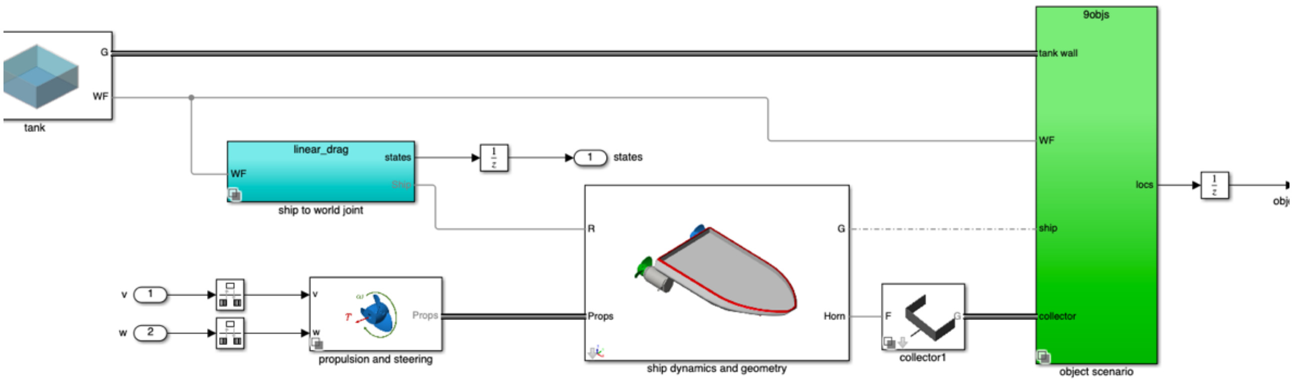

Figure. 1 Simulation modeling environment

The procedure continues via modeling interactions with the maritime environment and starts with the definition of a physical model of the vessel, including the hull and propulsion. Implementing open- and closed-loop control systems, integrating sensors for autonomous navigation, and creating pathfinding algorithms to steer the vessel toward trash are important components. Furthermore, modeling is essential to guarantee that the debris-collecting mechanism operates well in unison with the ship's motion and control system. Simulink simulations are crucial for evaluating the ship's performance, emphasizing enhancing the control strategy and design to increase efficacy and efficiency. This method incorporates dynamic control and intricate physical modeling.

To ensure that this ship is fully physically structured, the movement of this ship is not simply a matter of setting its xy coordinates. It has a hull and then two propellers on the hull. Two motors drive these two propellers, also simulated in Simulink. It needs to be manipulated by PWM, using the PWM duty cycle to generate a target thrust. Before the two inputs corresponding to the two motors, they have to go through a motor mixer, which can control the speed and direction of the boat by the two parameters, v, and w. The motor mixer simply means that the steering is achieved by the difference in speed between the two propellers, and it can ensure that when there is no w parameter, the two propellers can be steered by the difference in speed between the two propellers. It can be guaranteed that when w is equal to 0, there is no speed difference between the two propellers[6].

Need to design decision-making component. This part is crucial and is the main purpose of this ship design simulation. Need to find an efficient automated control in this process. In the above description, two variables can determine the speed and direction of the boat, so in the automation control part, only these two variables need to be adjusted.

When designing automated control systems, two important concepts need to be learned. They are feedforward and feedback control. Open-loop (feedforward) control requires knowledge of the global situation but does not require sensors; closed-loop (feedback) control requires sensor measurements and is self-correcting and rejects disturbances. Feedback control combined with feedforward control can significantly improve controller performance.

The ship must make real-time decisions based on current conditions in a dynamic marine environment. This could involve adjusting its path for efficiency or avoiding obstacles. So, more feedback control systems should be used.

After the design of the environment, the vessel, and the vessel controls are complete, there is one more thing that is important to analyze the results: the plotter. It shows everything that exists, generating a top-down view that includes the pool's edges, the vessel's real-time position, the target floating blob, and the path the vessel has taken. The efficiency of each automated algorithm can be better analyzed, as Figure 2 shows.

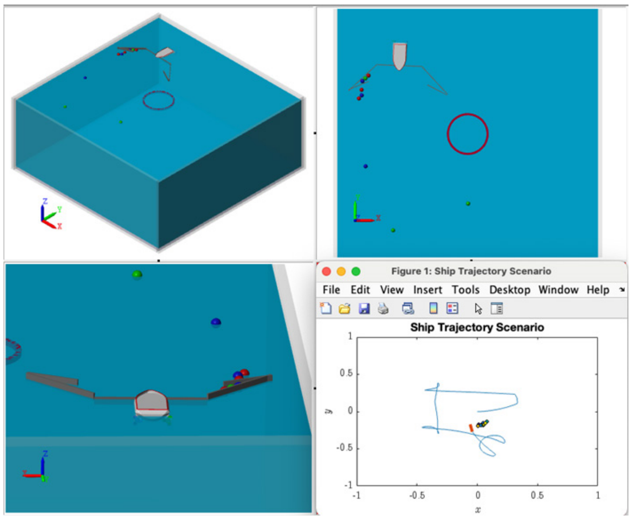

Figure. 2 Ship trajectory monitor

To achieve the effect of simulating the automated travel of a ship, modeling of the going target is also required. Set up ten randomly positioned floating balls on this pool that can be collected as the ship passes. For statistical purposes, set up ten different scenarios with differently placed balls.

3 Practical Prototype

3.1. Concept Design

The first step in creating a prototype is to define its function and purpose. This is done to ensure that the prototype is feasible. Its abilities must encompass floating, forward motion, maneuvering, and—above all—the ability to gather floating things while moving.

Drawings and conceptual layouts are crucial throughout the design process, and they should include dimensions, forms, and fundamental elements like the hull, decks, and any unique debris collection systems. The hull's strength and balance must also be considered throughout this process. Simultaneously, the type of transmission structure to be used—a monohull boat or a catamaran boat—must be considered.

3.2 Detailed Design

Fusion 360 was utilized for modeling in this process, and CAD modeling proved to be highly helpful in fabricating this prototype. With it, you can build intricate three-dimensional models of ships that include every part, including the hull, propeller, rudder, and any specialized machinery like trash collectors [7].

Next comes material selection, wherein lightweight plastics or composites appropriate for the scale model are chosen, considering attributes like buoyancy, durability, and ease of manufacture. Because the center of gravity has a major influence on a boat, weight is another crucial consideration.

3.3 Propulsion and Control

The propulsion system's design is crucial since it directly affects how well the ship operates. Two engines and two air propellers power it. Ensure the system is adequately sized for the model during the design phase.

Two Arduinos are employed in the design of the control system. To transmit control instructions, one is converted into a controller. There's another one on board, controlling the two motors [8]. The ship's steering may be accomplished by varying the speeds of the two motors.

3.4 Production

3D printing is used to manufacture the main body and its components. Complex components and connectors for safe electronic modules are made using 3D printing. Care must also be taken during the production process to keep the electronic components unaffected to guarantee that the hull is waterproof. Install the control electronics, battery, and motor. Once these parts are installed, ensure the boat is sturdy and balanced. As the figure 3 shows.

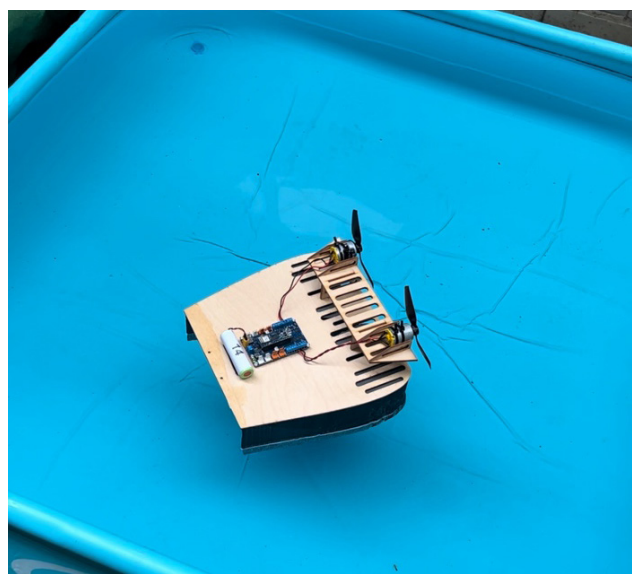

Figure. 3 Assembled prototype

3.5. Test and Iterate

The initial testing aims to evaluate the vessel in a controlled aquatic environment. Verify the remote control, propulsion, buoyancy, and maneuverability.

Make incremental improvements and any required hardware or design changes based on test results. This could entail modifying the control system for more responsive handling or the hull design for improved stability.

3.6 Debris Collector

A collector must be fitted if the ship is to be used for collecting debris. There is room between the two cabins because this design is a catamaran. Make it a collector of this ship by altering it [9].

4. Analysis of the System's Configuration

The Arduino Nano 33 IoT board is the ship's central processing unit, chosen for its compact size, IoT capabilities, and versatility in interfacing with various sensors and actuators. Its built-in Wi-Fi is utilized for remote data transmission and control. Complementing this, the Arduino Nano Motor Carrier allocates more voltage to the motor, simplifying motor control and sensor integration. It is designed specifically for the Arduino Nano and offers convenient connections for motors, servos, and sensors, streamlining the wiring and setup process[10].

A breadboard is a platform to connect the Arduino Nano with a joystick module, forming the ship's remote controller. The joystick module is ideal for manual control, allowing intuitive control of the ship's movement and providing a simple interface for direction and speed adjustments.

For power, the ship uses a Battery 18650 with an XT30 Connector, chosen for its balance of size, weight, and power capacity. This standard, rechargeable lithium-ion cell provides reliable power to the project, and the XT30 connector ensures a secure and stable electrical connection. DC motors are the primary drivers for propulsion, selected for their simplicity, ease of control, and effectiveness in providing the necessary thrust or movement for the ship. Servomotors are used for precise control of moving parts like rudders or other steering mechanisms, ideal for tasks that require accurate positioning and essential for controlling the ship's direction.

5. Conclusion

Human health and marine ecosystems are seriously threatened by the growing problem of marine pollution, which is typified by a large amount of plastic trash and chemical pollutants. An important step forward in addressing this is the creation of an automated, unmanned marine debris collection vessel. This work has investigated the complex procedure of creating and evaluating such a vessel using Arduino-based control systems and dynamic modeling with MATLAB Simulink. Simulating the ship's interactions with the marine environment, including hydrodynamic forces and debris collection mechanisms, required a thorough modeling approach in Simulink. This made it possible to improve the vessel's control approach, which used both open- and closed-loop technologies to maximize the effectiveness of trash collecting and pathfinding.

The working prototype of this vessel was created using cutting-edge technologies, including 3D printing and Arduino-based control systems. It went through several stages of development, from concept design to detailed design and manufacture. This prototype shows the viability and efficiency of such a vessel in practical situations. It is driven by DC motors and operated by servomotors and a joystick module. This study shows how control systems and modeling may be combined to produce novel responses to environmental problems. To lessen the effects of marine pollution and preserve marine life and ecosystems for future generations, the unmanned automated marine debris collection vessel offers a promising solution.

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