An IoT-Based Autonomous System for Oil Spill Detection

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Received 22 May 2024; received in revised form 19 July 2024; accepted 20 July 2024

DOI: https://doi.org/10.46604/emsi.2024.13760

Abstract

Oil is a vital global energy source, yet oil spills pose severe threats to marine and human life, causing significant economic, environmental, and social impacts. The dense consistency of crude oil complicates the cleanup of oceans and seabeds. To address this issue, an autonomous system utilizing IoT technology has been developed to efficiently remove crude oil debris from water surfaces. This innovative system skims the oil layer and simplifies the cleanup process. Performance tests at a constant rotary speed of 18 rpm showed an average removal rate of 107.88 ml/min of oil. They are increasing the number of rotary discs notably improved efficiency, doubling the oil collection with each additional disc. Leveraging IoT technology allows remote operation and real-time data monitoring via a mobile app. This solution offers a sustainable and eco-friendly approach to oil spill cleanup, making it particularly valuable for Bangladesh's context due to its viability and cost-effectiveness.

Keywords: Oil Skimmer, Crude Oil, TDS Sensor, Automatic Cleaner

1. Introduction

Energy consumption has greatly intensified in the modern day because of increasing globalization, rising population, and worldwide economic development. Therefore, the ocean is a vital form of transportation for the movement of more than 80% of various sorts of cargo. The development of maritime operations has resulted in a rise in oil spill incidents which cause vast amounts of oil to spread in water. Oil spillage is not a modern incident, it has been occurring for a long time. According to the International Tanker Owners Pollution

Federation Limited (ITOPF), approximately 5.86 million tons of oil have been lost as a result of tanker incidents in the marine environment in the last 50 years, and an average of over 7 tons of annual oil split from the tankers [1]. In the ever-changing maritime landscape, a series of significant events have unfolded, leaving an indelible mark on the course of history [2]. In addition, in 2014, due to an accident with an oil tanker on the Shela River in Sundarbans, Bangladesh around 350 tonnes of furnace oil spilled and spread over a 350 square km area [3-4]. As a result, a tragic consequence had come over this area's marine ecosystem and biodiversity S[5-6].

To save the environment and aquatic animals, local people risked their health to remove this spilled oil from the water surface with their bare hands and after that faced various types of skin diseases [6]. Numerous methods are available to eliminate floating oil from water, but studies show that the oleophilic system is a more efficient and convenient method than others, and the rest of the methods are quite expensive since they require a lot of skilled manpower and heavy equipment [7].

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English language proofreader: Hao-Lun Chang

Moreover, in the case of more efficient solutions, the mechanism for oil removal is more complex. Several researchers conduct their research on oil skimming systems to remove oil from the marine surface. Researchers are still trying to increase efficiency and find a convenient method for the oil spill. To investigate further, Choi et al [8] developed a system that is not autonomous and used BLE 4.0 as communication which works up to 100 meters where the user could control a limited area. Khandakar et al [9] worked on an efficient and low-cost mechanical-based blanket belt oil skimmer solution made from locally available parts.

However, the system is not suitable for working in the water and needs to be driven fully system by the human hand which is labor-costly. Dawood and Algawi [10] developed a mechanical belt skimmer system where the motto is removing spilled oil with less time, less personal effort, and less cost. A belt-type oil skimmer was developed by Mathews et al [11] where to obtain sustainable development, a photovoltaic cell was used as a power source. Shirbhate et al [12] developed a disc-type oil skimmer robot. However, due to the use of Bluetooth technology for controlling purposes, the device had an issue with distant operations (more than 9 meters). Manivel et al designed [13] a boat-shaped drum oil skimmer system that roller coated with Teflon or activated carbon.

From this perspective, Supriyono and Nurrohman [14] presented an innovative approach by designing a rotary disc oil skimmer that utilized a radio communication system, Arduino Mega as the main processing unit, and DC motors for operation. Although their work demonstrated significant advancements, the absence of an autonomous system limited the ability to detect oil spills remotely, requiring physical intervention to identify the accident location. Khan et al [15] developed a two-circular disc oil skimming system with good efficiency, incorporating IoT-based motor control and data monitoring. The system includes additional features such as a weather monitoring system with temperature, humidity, and moisture sensors, and utilizes two gear motors for disc control. However, the study lacks discussion on oil spill detection and system navigation, which are crucial aspects of the overall system functionality.

Walaa Sabbar et al [16] developed a cylindrical shape drum oil skimmer and examined the considered variables such as temperature, drum speed rotation, and oil viscosity affect the oil recovery rate. In [17] authors Saranya et al proposed a designed and developed belt skimming-based automated oil recovering system where Raspberry Pi is used as the main controller and pH, MQ3, and ultrasonic sensors are used for oil detection purposes. Saleh et al [18] conducted research aimed at enhancing the capability of oil skimmers by developing a sensing system to measure the width of the oil spill layer. The skimmer device was designed to skim the surface area based on the information obtained from the spill layer.

The research incorporated float and drum skimmers, with data processing carried out by a microcontroller and data transmission facilitated by XBEE modules. Despite the novel oil spill thickness sensing system, the system still requires manual control. McKinney et al and ITOPF suggested that in the oleophilic method, the disc system is commonly used for its advanced capabilities like capturing large surface area, non-clogging, higher oil recovery rate, and low maintenance cost to collect oil [19-20]. On the other hand, Plaza-Hernández et al, Liu et al, and Huang et al worked on IoT that plays a significant role in the maritime industry in the industrial 4.0 era [21-23]. The Internet of Things (IoT) is a combination of physical objects that relate to sensors, controllers, software, actuators, and other parameters built in. As more devices are dependent on the internet connection, demand for IoT has been rising significantly in recent years. Currently, IoT has already played a substantial role in different fields like IoT-based fish farming [24], air quality monitoring [25], and the power sector [26-27].

While researchers have made efforts to increase efficiency and find convenient methods for oil spill removal, many systems still lack autonomy and rely on manual control in the era of “Industrial 4.0”. Limitations such as limited control range, labor-intensive operation, absence of remote oil spill detection, and insufficient discussion on important aspects like system navigation and oil spill detection were observed. Additionally, the need for physical intervention to identify accident locations and the requirement for manual control in the presence of novel sensing systems highlight areas for further improvement.

The current methods for oil spill cleanup, including mechanical recovery, chemical dispersants, and bioremediation, exhibit significant limitations. Mechanical methods, while effective, are labor-intensive and inefficient in rough sea conditions. Chemical dispersants can be detrimental to marine life, and bioremediation is slow and unpredictable. Previous studies have proposed semi-autonomous skimming devices that lack real-time monitoring and adaptive control. This research addresses these gaps by developing an IoT-based autonomous system for oil spill detection and cleanup.

The primary problems tackled in this work include the inefficiency of manual oil skimming methods in turbulent waters, the absence of real-time monitoring and data collection in existing autonomous systems, the inability to adapt to varying drill conditions, and the high operational costs and environmental impact of traditional methods. By integrating IoT technology, this system enables real-time data monitoring and remote operation, significantly enhancing the efficiency and adaptability of the cleanup process. Despite advancements in oil spill cleanup technologies, traditional mechanical methods remain labor-intensive, and autonomous skimmers lack real-time adaptability and efficient data communication. This research bridges these gaps by introducing a fully autonomous, IoT-integrated system that enhances efficiency, adaptability, and operational control.The goal of this research is to design and implement an IoT-based autonomous sea surface oil cleaner with novel oil detection and a reliable, viable, sustainable oil skimming system.

The system will use a TDS sensor to detect the presence of oil on the water's surface and a motorized disc for skimming to remove the oil from the surface and transfer it to a reserve tank. For safe and effective operation, the system will also include vessel navigation components and the system will also be equipped with a camera for visual observation and control. Developed an Android app for monitoring and remote controlling purposes which makes it an all-in-one solution for combating water pollution caused by oil spills. This suggested system would be affordable without sacrificing high-quality instruments, a sustainable and workable system that would be invaluable in detecting the parameters in oil-split water. The primary contributions of this research encompass the development of an IoT-based autonomous system designed to enhance the efficiency of oil spill detection and cleanup.

This system integrates real-time data monitoring and remote control capabilities via a mobile application, allowing for streamlined operation and oversight. Furthermore, the implementation of multiple rotary discs has been employed to significantly improve oil collection efficiency. The system's performance was validated through experimental simulations, which demonstrated a substantial improvement in oil skimming efficiency, confirming the system's efficacy and potential for real-world application.

2. Proposed System Methodology

Fig. 1 shows the proposed automated marine surface oil cleaner block diagram which is designed for many different detecting, controlling, and monitoring systems. According to this block diagram, the overall system was operated. In oil detection, a servo motor connected with the Arduino Mega 2560, controls the continuous up and down movement of the total dissolved solids (TDS) sensor in between the water surface. This total dissolved solid sensor renders the value of TDS to the Arduino Mega and the TDS values are updated on the user server through the ESP-01 Wi-Fi module.

In the oil skimming system, one 12V DC motor is connected to the Arduino microcontroller through a driver circuit which physically rotates three rotary discs based on the outputs of the TDS sensor.These rotary discs are equipped with scrapers to remove oil from the discs to the reserve tank. An ultrasonic sensor connected to the Arduino microcontroller will notify if the oil inside the reserve tank exceeds the capacity. Thus, oil skimming can be controlled. Also, the reserve tank conditions will be automatically updated on the user server through the ESP-01 Wi-Fi module.

Regarding vessel navigation, two 12V DC motors are connected to the Arduino microcontroller through driver circuits which physically rotate the propellers to move the vessel forward or backward based on the user command. To rotate the vessel right or left, two servo motors are connected to the Arduino microcontroller, these can precisely rotate two rudders connected with the hinges to rotate the vessel right or left based on the user's command.

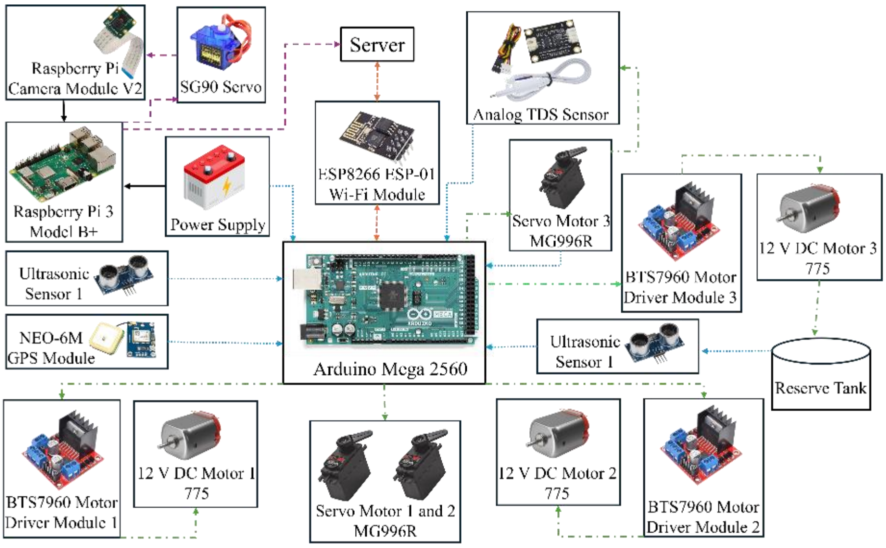


Fig. 1 Block diagram of proposed automated marine surface oil cleaner

Moreover, the Neo-6M GPS module is used to update the exact longitude and latitude of the vessel to the server. To avoid any unwanted collision another ultrasonic sensor is connected to the Arduino microcontroller. For visual observation, a camera is connected to the Raspberry Pi, a Linux-based single-board computer, which streams the surrounding video to the user server for visual observation. To control the camera’s movement another servo motor is connected.

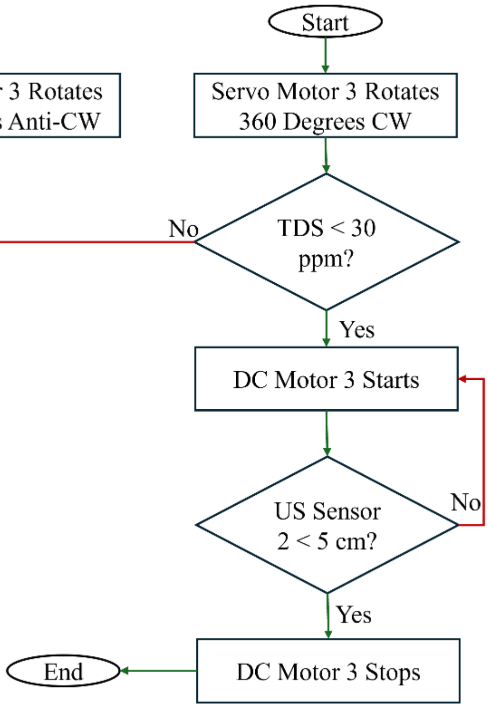


Fig. 2 Flow chart of the oil detection and the skimming unit

In oil detection, the servo motor 3 connected with the Arduino Mega, is initialized with continuous up and down commands. Where, if servo motor 3 goes 360 degrees clockwise, then it will rotate back 360 anticlockwise to its. initial position. And thus, it will continue the loop. For up-down movement; TDS can only measure the water TDS value while submerging under the water. However, for any water body, this TDS value cannot be less than 30 ppm. But if any oil spillage occurs in the marine environment, the TDS value will be fixed to a certain value which will be less than 30 ppm. Now if the TDS value is found as less than 30 ppm, the DC motor 3 will start to rotate and rotate until the ultrasonic sensor 2 reading is less than 5 cm. This ultrasonic sensor is placed above the storage tank. Fig. 2 flow chart shows the oil detection and the skimming system.

3. Proposed System Model

Fig. 3 depicts the 3D design with the proper architecture of the proposed disc-based oil skimming system. This device is modeled in such a way that it can hold the skimming discs along with the shaft and two hulls to balance the device properly, which are 3.5 feet long, 14 inches wide, and 8.5 inches high. In addition, the discs for oil skimming have a diameter of 14 inches and a thickness of 4 mm, and the oil storage tank dimension is 1.42 feet long, 4.7 inches wide, and 10 inches high. This designed prototype can be capable of holding up to 11.89 liters of oil. Furthermore, accumulating all-in-one devices can effectuate itself as an efficient prototype mode for oil skimming.

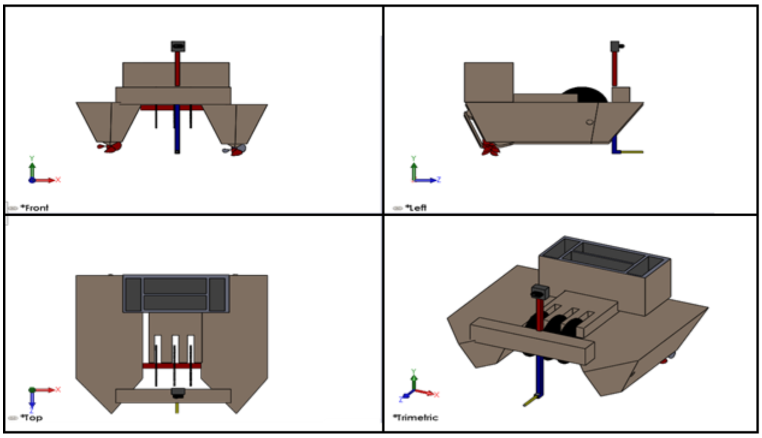


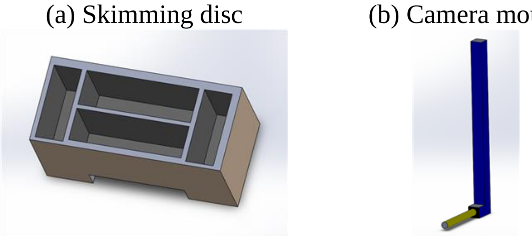
Fig. 3 3D model of the proposed system from different angles

In addition to the comprehensive 3D view presented in Fig. 4, the system comprises essential components such as the skimming disc, camera mount, sensor holder, and an intricately designed oil storage unit. Fig. 4(c) is an oil storage that is 2 feet long, 11 inches wide, and 11.4 inches high. However, inside the storage, there are four different chambers. The smaller chambers on the right and left are dedicated to wiring arrangements, while the two central chambers serve as designated spaces for oil storage. The front oil storage is used as secondary oil storage and the back oil storage is used as primary oil storage. The dimensions of the oil storage are 1.42 feet long, 4.7 inches wide, and 10 inches high. The overall oil storage capacity is calculated based on equation (1) shown below,

$$L = \frac{Volume\,in\,Cubic\;feet}{0.035315} \tag{1}$$

Where L represents the volume of oil storage capacity in liters, dividing the volume in cubic feet by the conversion factor of 0.0355.

(a) Skimming disc (b) Camera mount



(c) Oil storage tank (d) TDS sensor holder

Fig. 4 Different sub-components of the proposed system.

Therefore, this designed prototype can carry up to 11.89 liters of oil. To facilitate optimal functionality, a camera mount is securely affixed above the electrical component setup box, while a TDS sensor holder is positioned below the electrical components setup box on the front side of the two hulls. These strategic placements ensure seamless integration of the camera and TDS sensor, further enhancing the system's surveillance and oil detection capabilities.

4. Circuit Diagram & Hardware Prototype

Overall automated marine surface oil cleaner has been performed with the simulation software Proteus and Arduino IDE software. Fig. 5 shows that the whole simulation different types of systems were simulated, for example, navigation system, oil skimming system, storage management system, and obstacle avoidance system. The overall simulation was implemented with Proteus Software which is used inside the C++ coding.

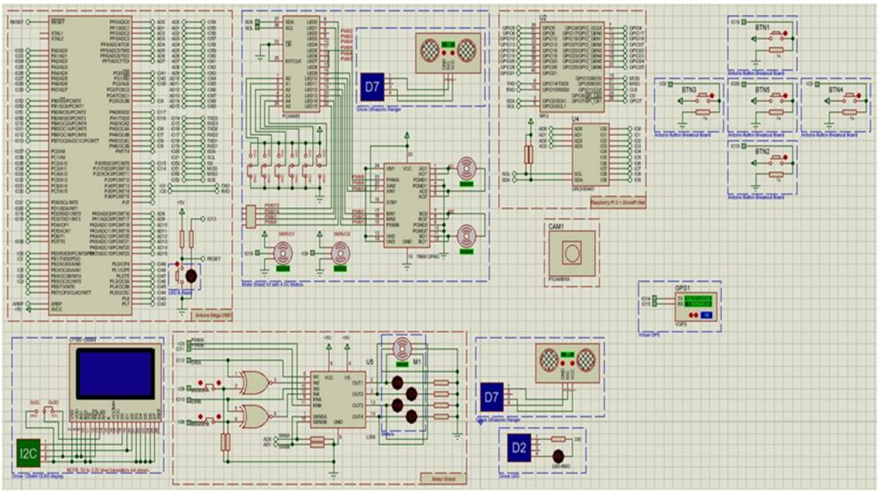


Fig. 5 Overall simulation diagram of the proposed system

The IoT-based navigation can enable the user to navigate the devices remotely without having to physically control the device. A single microcontroller, Arduino Mega, was used to design the navigation system. In this part, there were two DC motors and two servo motors used. However, currently, there was no library for the ESP 01 Wi-Fi module found. Therefore, to navigate the device the required commands were sent through the interrupt pins of the Arduino. So, to enable the interruption there were four momentary push buttons used.

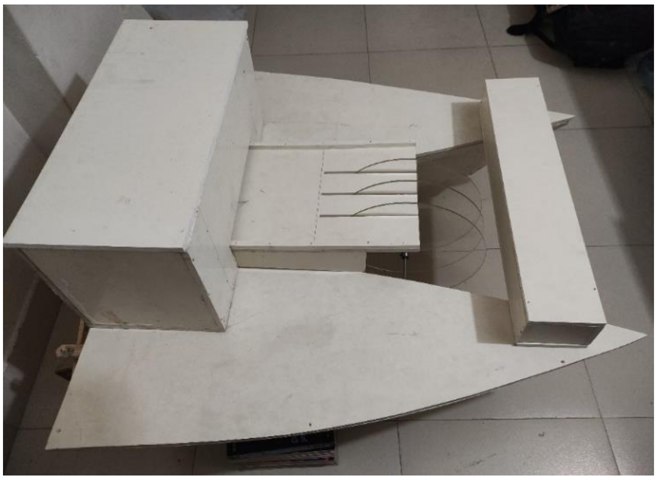


Fig. 6 Full hardware structure of the proposed system

For the skimming system, the same microcontroller as for the navigation system was used. To rotate the skimming discs, in the simulation, there were two DC motors used. However, in the hardware, to detect the oil the TDS sensor was used. But for simulation purposes, there was no library for TDS sensors found. Therefore, the skimming motor was controlled manually using a momentary push button. In addition, an OLED display and an ultrasonic sensor were used to observe and automatically control the motor in case of storage-overloaded conditions. However, some additional features have been added to the system, for instance, an obstacle avoidance system using an additional ultrasonic sensor, GPS tracking system, and so on.After simulating the whole system, the device was implemented physically. Fig. 6 shows the hardware implementation was done according to the 3D model and the circuit was built according to the Proteus simulation diagram. Practically the performance of the system was very close to prediction and the system worked without any trouble. There are two parts of the hardware system: navigation control, other, oil detecting, and skimming control.

In navigation, two 12V Lead-acid batteries were used since the overall project power consumption is quite high. However, to adjust the voltage level according to the servo motor and the 12 V DC motor, two step-down power modules were used. In addition, to control the DC motor more precisely, two BTS 7960 motor drivers were used. Control the device from a remote area over a WiFi network, an ESP-01 WiFi module was connected to Arduino. In the hardware for oil detection, the most significant component is the TDS sensor, which can continuously maintain the up-down movement through a servo motor.

5. Power Consumption and Battery Life Analysis

Table 1 renders a detailed breakdown of the power requirements for each component used in the IoT-based autonomous system for oil spill detection.

Table 1 Power Consumption of the Proposed Model

Component Name	Quantity	Voltage (V)	Current (A)	Power (W)
775 DC Motor	2	12	1.95 (75 % load)	46.8
BTS7960 Motor Driver	2	12	0.2188	5.25
MG996R Servo Motor	2	6	0.75 (30 % load)	9
Total (Navigation System)				**61.05**
Raspberry Pi 3 Model B+	1	5	0.6	3
Raspberry Pi Camera Module V2	1	3.3	0.25	0.825
SG90 Servo Motor	2	5	0.1	1
Total (Visual Monitoring)				**4.825**
TDS Sensor	1	5	0.006	0.03
MG996R Servo Motor	1	6	0.75 (30% load)	4.753
Total (Oil Detection)				**4.783**
775 DC Motor	1	12	1.8 (moderate load)	21.6
BTS7960 Motor Driver	1	12	0.2188	2.63
HC-SR04 Ultrasonic Sensor	1	5	0.065	0.325
Total (Oil Skimming System)				**24.55**
Arduino Mega 2560 Rev3	1	5	0.05	0.25
GPS Module GY-NEO-6M V2	1	5	0.05	0.25
HC-SR04 Ultrasonic Sensor	2	5	0.065	
ESP8266 ESP-01 WiFi Module	1	3.3	0.08	0.264
Total (Additional Components)				**1.414**
Total Power Consumption				**95.127**

Each component is listed along with its quantity, operating voltage, current, and power consumption. The power consumption is calculated based on typical operational conditions and load assumptions.The Navigation System includes two 775 DC motors, two BTS7960 motor drivers, and two MG996R servo motors. The total power consumption for this subsystem is approximately 61.05 W. The Visual Monitoring system consists of a Raspberry Pi 3 Model B+, a Raspberry Pi Camera Module V2, and two SG90 servo motors, with a total power consumption of approximately 4.825 W. Concerning Oil Detection, a TDS sensor, and an MG996R servo motor are used, resulting in a total power consumption of approximately 4.783 W. The Oil Skimming System contains one 775 DC motor, one BTS7960 motor driver, and one HC-SR04 ultrasonic sensor, with a total power consumption of approximately 24.55 W. Finally, the Additional Components include an Arduino Mega 2560 Rev3, a GPS Module GY-NEO-6M V2, two HC-SR04 ultrasonic sensors, and an ESP8266 ESP-01 WiFi module, resulting in total power consumption of approximately 1.414 W. Overall, the total power consumption of the entire system is approximately 95.127 W, considering all components and their operational conditions.

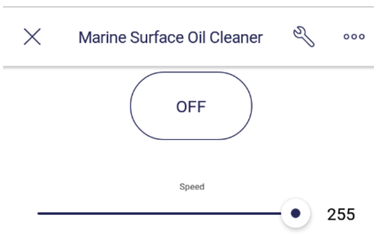
The power supply for the system is provided by two 12V, 7.5Ah lead-acid batteries, yielding a total energy capacity of 180Wh. The operational duration of the batteries is influenced by the varying power demands of the system's subsystems. The navigation, oil skimming, and oil detection subsystems are not concurrently active at all times; navigation and oil detection are operational during movement, while oil skimming is active independently. Consequently, the system's power consumption fluctuates based on the mode of operation. Under a moderate workload, the overall power requirement is approximately 95.127W. Given the total battery capacity, the system can operate for approximately 1.9 hours before requiring a recharge. This estimation provides a practical understanding of the system's endurance in real-world conditions, considering the intermittent activation of different subsystems.

6. Performance Evaluation of the Prototype

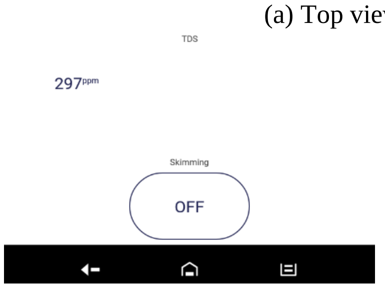
The developed system harnesses the power of IoT technology, utilizing the user-friendly Blynk app as its IoT platform for seamless navigation, control, and monitoring. Within the Blynk environment, specific virtual pins have been assigned to perform designated operations, ensuring a streamlined and efficient user experience.

6.1. GUI Interface

In the app monitoring section, Fig. 7 shows the oil detection output of the Blynk app. Initially, before mixing the oil with water, the TDS value fluctuated between 280 ppm to 300 ppm. And the oil skimming system did not activate but after mixing the furnace oil, the TDS value started to fall and was finally set to 0 ppm.



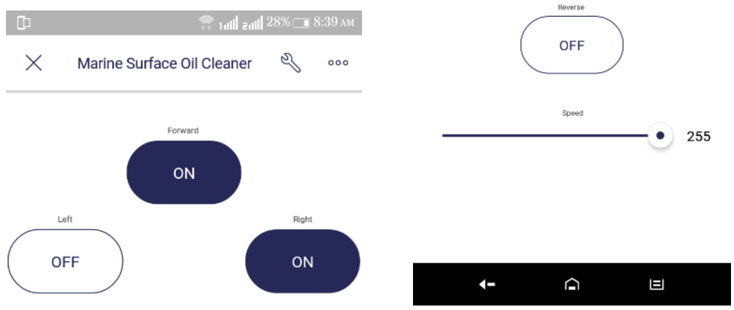
(a) Top view of Blynk app output



(b) before mixing the oil (bottom view) (c) after mixing the oil (bottom view)

Fig. 7 Left to Right Blynk app output

Since both the electrodes of the TDS sensor were covered with oil. Therefore, this sensor could not detect how much inorganic salts and small amounts of organic matter were present in the solution in water. Consequently, the skimming motor was activated to rotate the discs. Furthermore, in the Android app, Fig. 8 shows the navigation section. A total of four virtual pins, for instance, virtual pin 0 (V0), virtual pin 1 (V1), virtual pin 2 (V2), and virtual pin 3 (V3), are used to navigate the overall device as well as the dc motor. V0, V1, V2, and V3 are denoted in forward, reverse, turning left, and turning right functions, respectively in the Blynk app. Fig. 9 flowchart of the device navigation demonstrates how the virtual pins are used to manage the DC motor and steer the machine.



(a) Top View (b) Bottom View

Fig. 8 Blynk app navigation section of the proposed system

The user can navigate the device correctly with the guidance of this flowchart, which also explains the procedures needed to control the device's movement. The operator can quickly move the apparatus in different directions and effectively collect oil that has spilled with the aid of this navigational part. Overall, the navigation part of the Android app's virtual pins offers users a simple and convenient way to control the device using a mobile application. The user can be able to shift the system forward, backward, left, or right by providing values to the virtual pins on the water surface.

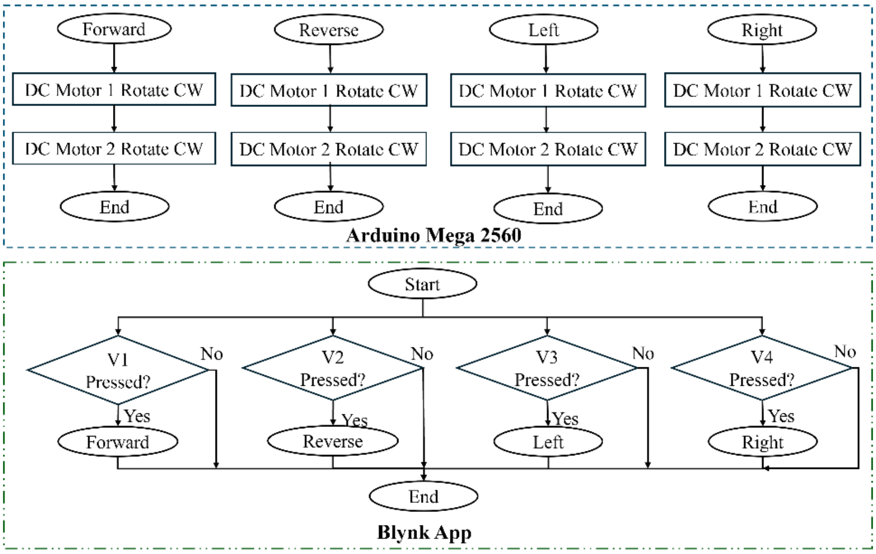
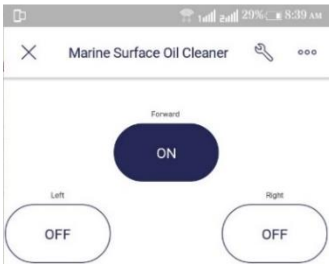


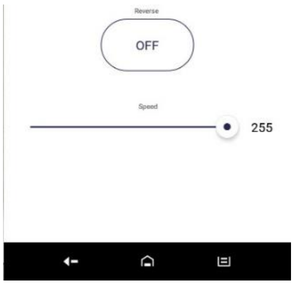
Fig. 9 Full control system flow chart of the vessel navigation system

6.2. Hardware Interface

In the hardware, Fig. 10 depicts, four navigation functions declared previously in the GUI section. In the forward function, both the DC motors 1 and 2 rotate clockwise, while in the reverse function rotating reverse. For the left function, both servo motors 1 and 3 rotate at an angle of 40 degrees, while for the right rotate at an angle of 160 degrees. Here, one important note is that both servo motors 1 and 2 are initiated at an angle of 100 degrees. This means that in any navigation function, the initial position of these two servo motors will be at 100 degrees. For example, in the left function, both servo motors 1 and 3 will move to an angle of 40 degrees from their initial position of 100 degrees, while in the right function, they will move to an angle of 160 degrees.

(a) Hardware components





(b) Top view of navigation system (c) Bottom view of navigation system

Fig. 10 Final output of device navigation system for movement

Fig. 11 presents a visual of the complete operation of the oil skimming system, showcasing the seamless functionality achieved through the meticulously designed hardware components. The hardware section of the prototype model is expertly crafted to ensure optimal navigation control, enabling the vessel to maneuver effortlessly in various directions. This harmonious integration of hardware elements ensures the smooth and efficient operation of the entire system.

Fig. 11 Oil skimming running on the developed hardware

The prototype utilizes two 12V, 2.6A 775 DC motors to facilitate forward and backward movement, necessitating approximately 62.4 watts of power. When unladen, the prototype weighs around 32 kg, achieving a rotational speed of approximately 200 RPM. Converting this to angular velocity results in 20.94 rad/s, leading to a calculated torque of 2.98 Nm. However, when the reserve tank is filled with crude oil, increasing the total weight to 43 kg, the prototype operates at around 250 RPM. Using the same method for torque calculation, this scenario produces a torque of 2.38 Nm.

6.3. Performance Analysis of Rotary Disc

The main purpose of the data analysis was to evaluate how effectively the oil-skimmer prototype separated oil from water. Two experiments were examined in this research, the first to see if the prototype could separate oil and the second to see what effect the number of rotational discs had on the volume of oil collected. For the first test, whether oil can be separated or not and determine the effect of the number of rotary discs with a fixed rotary speed of 18 RPM. The first test was carried out using one rotary disc. The data were taken times for the same period of 5 minutes. Table 2 shows the results of the oil skimmer testing using one rotary disc. The collected oil volume ranged from 496 ml to 607 ml, with an average speed of oil removal of 107.88 ml/min. These results indicate that the oil skimmer prototype is effective in separating oil from water.

Table 2 Oil skimmer test using one rotary disc

No	Amount of oil collected (ml)	Speed of oil collection(ml/minutes)
1	537	107.4
2	496	99.2
3	554	110.8
4	607	121.4
5	503	100.6
Average	539.4	107.88

The second test used two and three rotary discs to compare how much oil was collected depending on the number of rotary discs. The findings in Table 3 and Table 4 demonstrated that the volume of oil collected rose with the number of rotary discs, with the use of three rotary discs recording the maximum volume of oil collected. This implies that increasing the number of rotary discs can increase the efficiency of the oil skimmer prototype in separating oil from water.

Table 3 Oil skimmer test using two rotary disc

No	Amount of oil collected (ml)	Speed of oil collection(ml/minutes)
1	903	180.6
2	1207	241.4
3	1117	223.4
4	1319	263.8
5	1269	253.8
Average	1163	234.04

Table 4 Oil skimmer test using three rotary disc

No	Amount of oil collected (ml)	Speed of oil collection(ml/minutes)
1	1757	351.4
2	1972	394.4
3	1896	379.2
4	2284	456.8
5	2158	431.6
Average	2013.4	402.68

The average amount of oil collected and the average speed of oil collection employing one, two, and three rotary discs are shown in Figs. 12 and 13. The graphical representations provide a clear visual depiction of a consistent trend as the number of rotary discs increases, the amount of oil collected and the speed of collection both show notable improvements. Specifically, when utilizing a single rotary disc, an average volume of 539.4 ml of oil was collected at a flow rate of 107.88 ml/min.

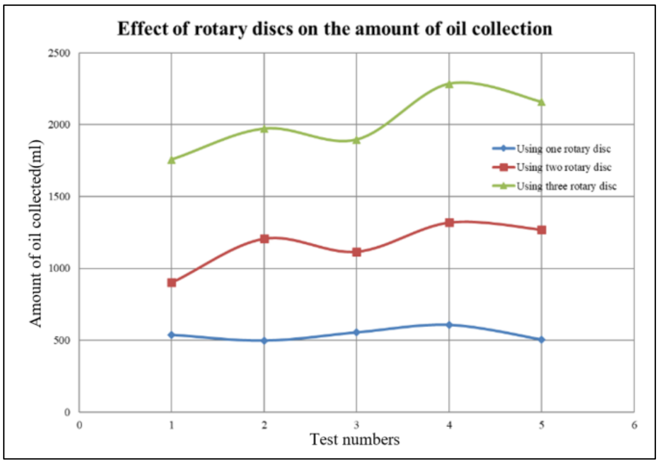


Fig. 12 Average amount of oil collected

With the implementation of two rotary discs, the average volume of oil collected increased to 1163 ml, accompanied by a speed of 234.04 ml/min. The utilization of three rotary discs yielded even greater results, with an average volume of 2013.4 ml of oil collected at an average speed of 402.68 ml/min.It is important to note that the efficiency and effectiveness of the oil skimmer are directly affected by the number of rotary discs used.

From the graphical analysis, it becomes evident that employing three rotary discs yields optimal performance in terms of both oil collection quantity and speed. Therefore, it is recommended to use three rotary discs for maximum efficiency. Additionally, the high speed of oil collection using three rotary discs indicates that the oil skimmer can effectively remove oil spills from water bodies in a relatively short amount of time.

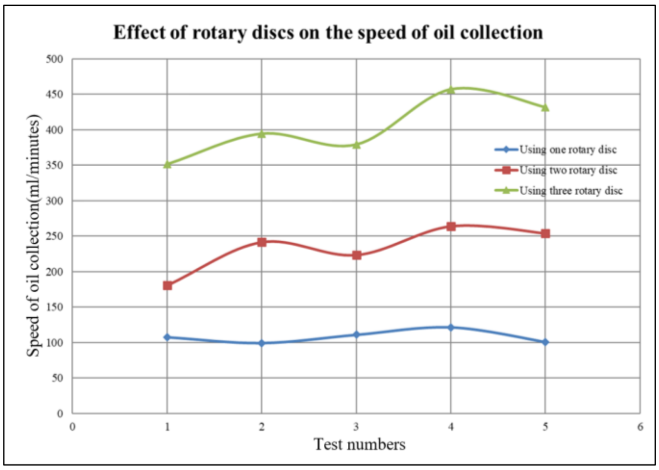


Fig. 13 Effects of selecting different switching under dynamic conditions.

One 12V, 2.6A 775 DC motor was used to rotate three rotary discs, consuming approximately 31.2 watts of power. The RPM of rotary discs was 18 RPM which was set for the precise collection of crude oil. So, the values of RPM and power provided a 16.55 Nm torque. In Fig. 14, the RPM versus collection of crude oil per minute was shown.

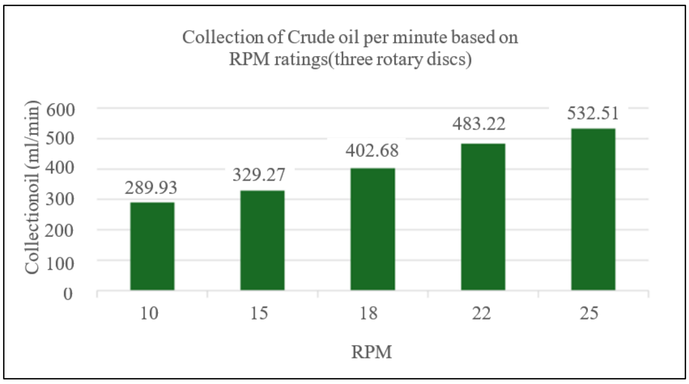


Fig. 14 Effects of collected crude oil based on RPM of the rotary disc.

Observing Fig. 14 it is clear that increasing RPM values provides the prototype to collect more crude oil per minute. However, for mechanical structure and precise crude oil collection rate, 18 RPM was set.

6.3. TDS Sensor Coverage and Practical Implementation

The TDS sensor utilized in this development features two electrodes positioned 2 cm apart. These electrodes can conduct electricity when submerged in a conductive medium. The sensor holder is designed to move continuously up and down, allowing the sensor to alternate between being submerged in water and exposed to the air.

Since oil has a lower density than water and always floats on the surface, the sensor will encounter the oil layer during its downward movement. As it moves through the oil and into the water, the sensor measures the Total Dissolved Solids (TDS) value. When the sensor's electrodes are coated with oil, the TDS value reads 0 ppm due to the lack of electrical conductivity.

Although a single TDS sensor was used to detect the presence of oil over an area ranging from 1 foot to 1.5 feet with three rotary discs, the detection capability is more dependent on the sensor's dynamic movement mechanism rather than the static coverage area. Therefore, in practical applications, employing multiple TDS sensors would enhance the system's readability and accuracy in detecting oil spills.

6.4. Discussion

Upon implementing various approaches, several results were obtained. The Graphical User Interface (GUI) displayed a decrease in the Total Dissolved Solids (TDS) value, which stabilized at 0 ppm when the water was mixed with furnace oil. To evaluate the separation of oil from water, the project's performance was tested at a constant rotary speed of 18 rpm. The findings indicated that, on average, 107.88 ml/min of oil was successfully removed from the water. Increasing the number of rotary discs significantly enhanced the efficiency of the oil skimmer prototype in separating oil from water. Specifically, each additional rotary disc resulted in an approximate 100% increase in oil collection. Therefore, it was concluded that the number of rotary discs utilized directly influences the efficiency and effectiveness of the oil skimmer.

While these results are promising, challenges arise when considering the implementation of the system in actual oceanic scenarios. On a seabed, the primary issue would be dealing with sea waves and currents, which can significantly impact the stability and functionality of the prototype. Precise navigation and control systems would be crucial for operating the prototype safely and effectively in the open ocean.

7. Conclusions

Oil spills are catastrophes that may have negative effects on society, the economy, and the ecosystem. In this research, an automated marine surface oil cleaner was designed and developed. The project is based on IoT. Despite some drawbacks, for instance, limited storage, semi-autonomous mechanism, and sensitivity to bad weather, all feasible actions culminated in the project's successful completion. The project's novel aspects were investigated and tried to implement. Some drawbacks can be acceptable considering the built system was a prototype. The findings of the project, studies, and further research all point to the large-scale production of automated marine surface oil cleaners with a novel idea practically in today's world. This could result in a revolution in the world's cutting-edge technology, as well as the economy and environment. Despite all the shortcomings of this research, the results and findings inspired us to improve this research further in the future.

In the future implementing a new flight controller to navigate the device autonomously can be a turning point. Currently, there is no weather monitoring system in this project. As a result, if the weather turns bad, the device might face some problems. Therefore, a weather monitoring system can be implemented to notify the weather conditions of the device location to the user. An AI Image processing-based oil area detecting system would be a game-changing solution. Finally, the storage capacity of this device should be increased with a considerable model.

Conflicts of Interest

The authors declare no conflict of interest.

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