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Autonomous Lake Surface Cleaning Machine

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Abstract: This paper presents research on the design and development of an autonomous machine for cleaning lake surfaces. The study aimed to solve three main problems: determining the appropriate motor size and body materials, designing an efficient motor control system, and implementing energy efficiency enhancement strategies. To address all problems, extensive analysis and calculations were conducted to select the optimal motor size based on factors such as weight, desired speed, and motor rating. Suitable materials were also evaluated for the machine's main body to ensure durability and buoyancy in a lake environment. A motor control system using an H-bridge design was developed to enable precise and responsive movement control for autonomous operation and optimized cleaning performance on the lake surface. Furthermore, energy efficiency enhancement strategies, such as utilizing an energy-efficient conveyor system, were implemented in the machine's design. The results demonstrate the achievement of the research objectives, including appropriate motor sizing and body material determination, efficient motor control system design, and the implementation of energy efficiency enhancement strategies. This encompasses sourcing and procuring components, assembling the main body, taking measurements, and undertaking troubleshooting and refinement efforts on the prototype. The developed machine has the potential to significantly contribute to the maintenance and preservation of lake ecosystems, addressing the environmental challenges associated with lake pollution.

Keywords: Autonomous Lake Surface Cleaner, DC Motor Sizing, H-Bridge, Movement Control.

1. Introduction

Water pollution, including lake contamination, is a significant environmental concern. At Universiti Tun Hussein Onn Malaysia (UTHM), an artificial lake suffers from pollution, affecting water clarity and aquatic life. To address this issue, the development of a lake surface cleaning machine is proposed. The machine would float on the lake and efficiently collect submerged plants and algae, helping to maintain water quality. Autonomous water quality monitoring and surface cleaning capabilities of unmanned surface vehicles (USVs) have been studied as potential solutions [1].

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DC motors are commonly used in control engineering due to their simplicity and excellent performance [2]. For battery-powered systems like robots, motors operating at 6, 12, or 24 volts are preferred. For instance, Helicopter organization is expanding, for example, the VSR700 project [3]. The power input and current rating of a motor are important indicators of its performance. Torque, measured in ounce-inches, indicates the rotary force exerted by the motor. Stepper motors are often used in precision positioning applications, such as computer hardware and robotics, where accuracy is crucial [4].

A motor control system regulates the operation of a motor, including its rotation, speed, torque, and protection against electrical failures and overloads. Different motor control components are utilized depending on the specific motor mechanism. Energy efficiency enhancement plays a vital role in various applications, including robotics, machinery, and industrial systems. The previous research was conducted to present the energy recovery in an electrical form supplied by the batteries of electrical vehicles [5]. By using less energy to perform tasks, such as heating, cooling, and manufacturing, energy-efficient solutions contribute to environmental sustainability and resource conservation. The paper authored by Researcher [6] presents a specification-based testing approach for polymorphic attributes. The authors focus on formal methods and software engineering. Focusing on discussions surrounding the societal, ethical, and cognitive aspects of informatics and information and communication technology (ICT) [7] is paramount.

The primary aim of this paper is to develop an autonomous lake surface cleaner capable of effectively cleaning the artificial lake situated in front of Block G3, UTHM. The objectives are to establish suitable motor sizing and materials, develop effective motor control systems, and apply energy-efficient enhancements for the design of an autonomous lake surface cleaning machine.

2. Materials and Methods

This section will discuss the mechanical, electrical, and mathematical calculation approach involving development and design to enhance the mechanism involved in this project and will demonstrate the complete system in detail with a flow chart and block diagram.

2.1 Overview of the research

The microcontroller used for the autonomous lake surface cleaner's DC motor movement control system is Arduino UNO. An ultrasonic sensor is connected to the Arduino UNO to enable lakeside detection. To control the speed and direction of two 12V DC motors independently, an L298N motor driver is employed as an H-bridge circuit. The h-bridge circuit switches the polarity of the output voltage to the DC motor for speed and direction control. Additionally, a current sensor is connected between the motor driver and the DC motor to provide overcurrent protection. Another L298N motor driver is utilized to control the stepper motor responsible for the conveyor system. It energizes the electromagnetic coil of the stepper motor. The overall system block diagram is depicted in Figure 1.

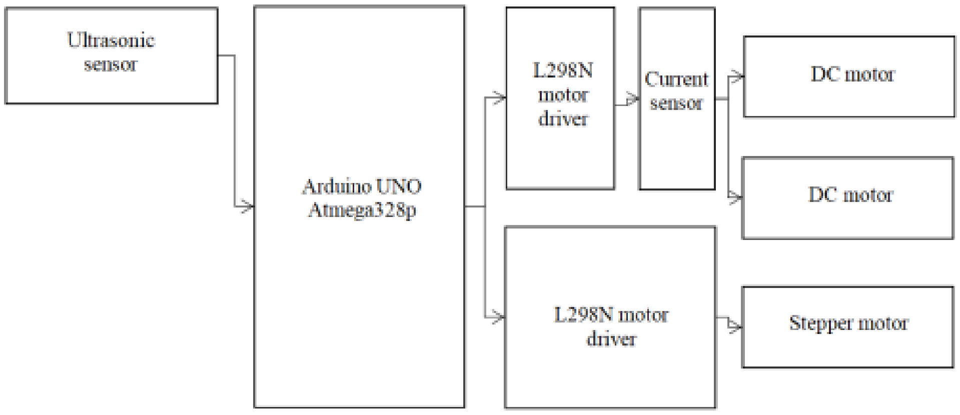

Figure 1: Overview system block diagram

2.2 Research flow

The flowchart in Figure 2 can be divided into four distinct phases: I, II, III, and IV, each represented by different-colored columns. Phase I involves designing the Autonomous Lake Surface Cleaner, including determining its dimensions, volume, weight, density, and buoyant behavior on water. In this phase, the initial step involves calculating the power needed for the full-size model to estimate the power requirement of the autonomous lake surface cleaner while considering system efficiency. Subsequently, the nominal voltage and current for the DC motor will be determined. Calculations for torque and speed requirements will follow. Based on these parameters, the motion control system will be designed, encompassing free body and control system diagrams, along with provisions for the braking and protection systems. To demonstrate the functionality of these systems, specialized simulation software will be utilized for circuit simulations.

In Phase II, the focus shifts to motor selection and motion control. Motor size is determined based on factors like power, torque, and speed, while a simulation-based approach is used to develop the motion control mechanism. Sub-section 3.3 explores the creation of braking and protection systems. In the motion design of the autonomous lake surface cleaner, pivotal components are the Arduino UNO microcontroller and the L298N motor driver. Pulse Width Modulation (PWM) is employed to regulate the DC motors. Adjusting the voltage via PWM alters motor rotation speed—higher voltage speeds it up, while lower voltage slows it down. The L298N motor driver is integral for the simultaneous control of speed and direction of two DC motors, enhancing the cleaner's movement control. Applying PWM to the driver governs motor speed, finely dictating cleaner motion. Tailoring left and right motor speeds independently enables diverse steering, facilitating versatile and accurate movement on the lake. In unison, the Arduino UNO, L298N motor driver, and PWM technique grant precise speed and direction regulation, ensuring effective motion control.

Energy efficiency takes center stage in Phase III. This phase entails measuring power consumption, creating a power-saving mode through simulation, and then implementing energy-efficient modifications into the model. For energy efficiency enhancement, the approach involves integrating a sleep mode concept into the autonomous lake surface cleaner, controlled by an Arduino UNO as the central system controller. This sleep mode allows the cleaner to enter a low-power state during periods of inactivity, conserving energy. By doing so, unnecessary power consumption is minimized, effectively improving overall energy efficiency. The project report will present comprehensive data and graphs comparing energy consumption before and after sleep mode implementation. This visual evidence will underscore the impact of the sleep mode on energy efficiency. Analyzing this data will gauge the effectiveness of the sleep mode in curtailing energy use. Through these optimization measures, particularly the incorporation of the sleep mode, the project endeavors to significantly boost the energy efficiency of the autonomous lake surface cleaner.

Lastly, Phase IV revolves around prototype production. This encompasses sourcing and procuring components, assembling the main body, taking measurements, and undertaking troubleshooting and refinement efforts on the prototype. In summary, these phases encompass the project's design, motor selection, motion control, energy efficiency improvement, and prototype fabrication aspects.

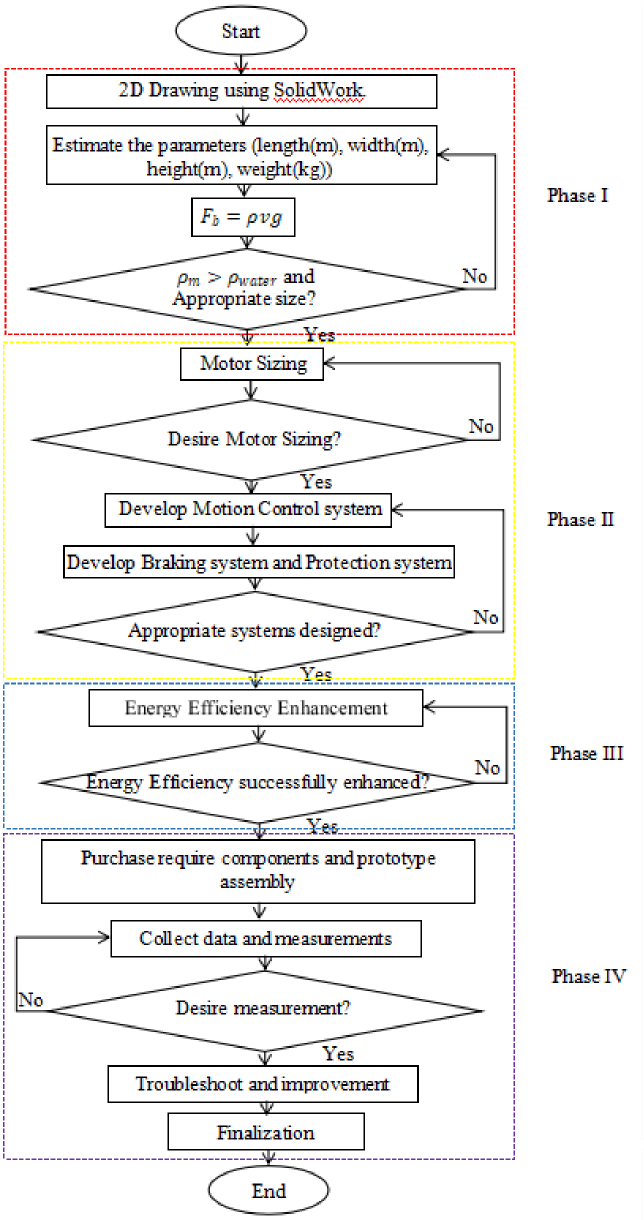

Figure 2: Summary of research flow

2.3 Hardware and components

The hardware and components installed in the prototype of the autonomous lake surface cleaning machine are described in this section. The microcontroller chosen for the system is Arduino UNO, while the L298N motor driver is utilized to construct the H-bridge circuit for controlling the speed and direction of the DC motors. The system is also equipped with an ultrasonic sensor for lakeside detection. To measure and sense the motor's current and provide overcurrent protection, a current sensor is incorporated into the design. Figure 3 illustrates the schematic diagram of the DC motor control system for an autonomous lake surface cleaner.

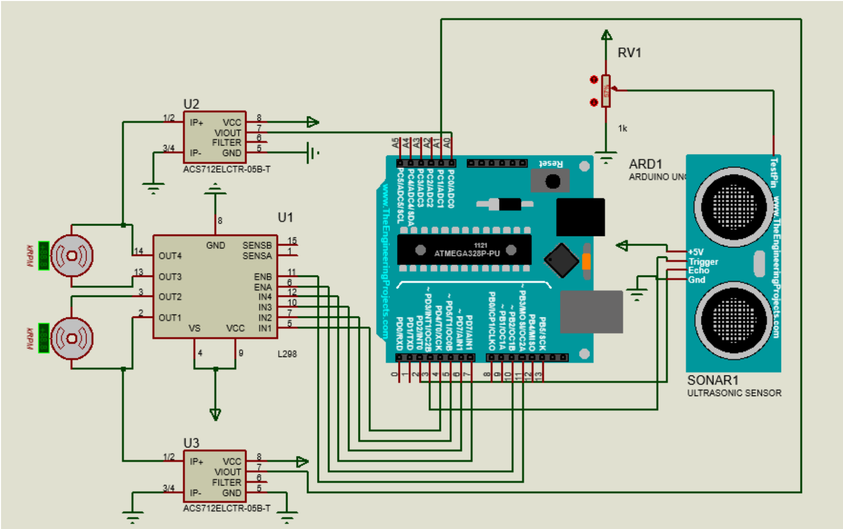

Figure 3: Schematic diagram of DC motor control

3. Results and Discussion

The results section will provide a comprehensive discussion of the theoretical framework and mechanisms utilized in the autonomous lake surface cleaner, by the stated objectives. The L298N motor driver is utilized to connect the two DC motors, and the power and direction control is achieved through the application of the Pulse Width Modulation (PWM) method. Furthermore, an energy efficiency enhancement strategy is implemented by designing a power-saving mode for the conveyor system, utilizing a sleep delay setting.

3.1 DC motor sizing

Table 1 provides the estimated values for the rated voltage, operating current, speed, shaft length, and shaft diameter. To enhance the propulsion of the autonomous lake surface cleaner, two DC motors will be installed on the left and right wings of the cleaner, generating additional force to propel it forward. The mechanical power required for autonomous lake surface cleaner and the torque required by the system are 0.024 W and 0.15 Nm which are obtained from:

$$P_{mechanical} = F_{res} v \qquad Eq. 1$$

Where,

$P_{mechanical}$ = Mechanical power required by the system

F_{res} = Resultant force

v = velocity

$$\tau = \frac{(I \cdot V \cdot E \cdot (60))}{2\pi(rpm)} \qquad Eq. 2$$

Where,

τ = Torque

I= Rated current

E= Efficiency

V= Rated Voltage

Rpm = Speed of DC motor

Table 1: Motor sizing estimation

Aspects	Specification
Rated Voltage	12V
Nominal Voltage	12V
Rated Current	0.75A
No Load Speed	9800rpm
Set Speed	300rpm
Rated Power	3.6W
Type	Brush DC Motor
Rated Torque	0.15 Nm

3.2 DC motor control system

The L298N motor driver [8] controls the power sent to the motors by adjusting the voltage applied to the enable pins. By increasing the voltage on the enable pin, the motor receives more power, leading to an increase in its speed. Furthermore, an ultrasonic sensor [9] is connected to the Arduino UNO to detect the presence of the lakeside. Figure 4 depicts the connection of the DC motor control system with the lakeside detection system. Table 2 provides the collected measurement data specifically for forward movement. To gauge the DC motor's voltage and current, voltage and current sensors are integrated. Measurements, including current, voltage, motor speed, and torque, are relayed through the serial monitor every 5 seconds. Forward movement's maximum speed employs a PWM value of 255, while reverse movement uses 155 PWM. PWM manipulates voltage and current by modulating pulse duty cycles. A reduced duty cycle curbs current and torque while maintaining voltage levels. For braking, dynamic braking is engaged, a conventional DC motor technique utilizing an H-bridge motor drive. It entails cutting motor power and relying on inertia and freewheeling diodes to dissipate stored energy extra components are needed beyond the motor driver. Also, a voltage sensor captures voltage and torque.

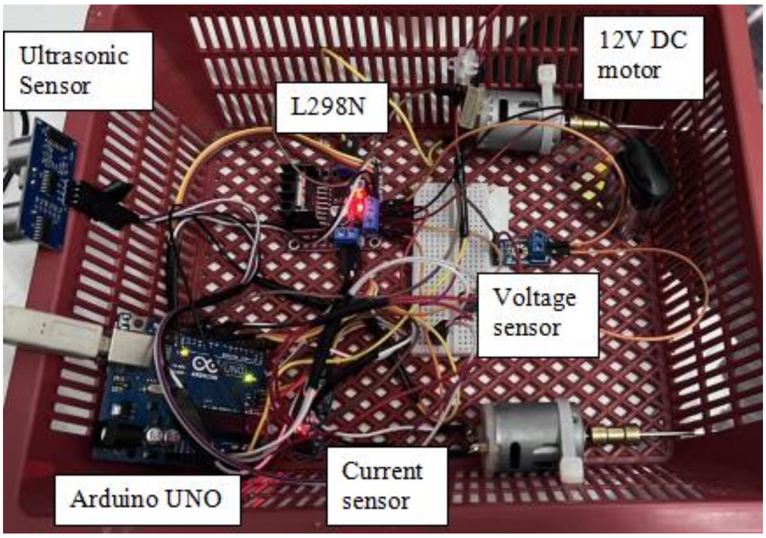

Figure 4: Connection of DC motor control system with lakeside detection system

Table 2: Measurements of DC motor for forward movement

Duration (sec)	Range (cm)	Voltage(V)		Current(mA)		Speed (PWM)		Torque (Nm)	
		Left	Right	Left	Right	Left	Right	Left	Right
0.0	22.0	11.18	11.12	692.0	682.0	255	255	0.63	0.62
5.0	24.0	11.33	11.31	693.0	690.0	255	255	0.63	0.63
10.0	29.0	11.25	11.25	691.0	687.0	255	255	0.64	0.63
15.0	29.0	11.33	11.25	690.0	691.0	255	255	0.64	0.63
20.0	22.0	11.30	11.29	692.0	689.0	255	255	0.64	0.63
25.0	22.0	11.28	11.27	693.0	687.0	255	255	0.64	0.63
30.0	23.0	11.33	11.30	690.0	690.0	255	255	0.64	0.62
35.0	24.0	11.30	11.33	693.0	688.0	255	255	0.64	0.64
40.0	23.0	11.35	11.34	689.0	689.0	255	255	0.64	0.63
45.0	28.0	11.30	11.39	692.0	687.0	255	255	0.64	0.63

3.3 Energy efficient enhancement strategy

A power-saving mode was designed and implemented in the control system of the stepper motor, utilizing Arduino Uno and a motor driver with sleep mode functionality. The sleep mode was activated with a sleep delay duration of 3 seconds, allowing the stepper motor to remain idle and conserve energy after completing a full revolution. Enabling the power-saving mode results in a reduction of approximately 16.35% in the average power consumption of the stepper motor. Specifically, the power consumption decreases from approximately 5.75 W to 4.81 W. Figure 5 illustrates the graph of power reduction for the stepper motor while Figure 6 shows the autonomous lake surface cleaning machine that has been used in this paper.

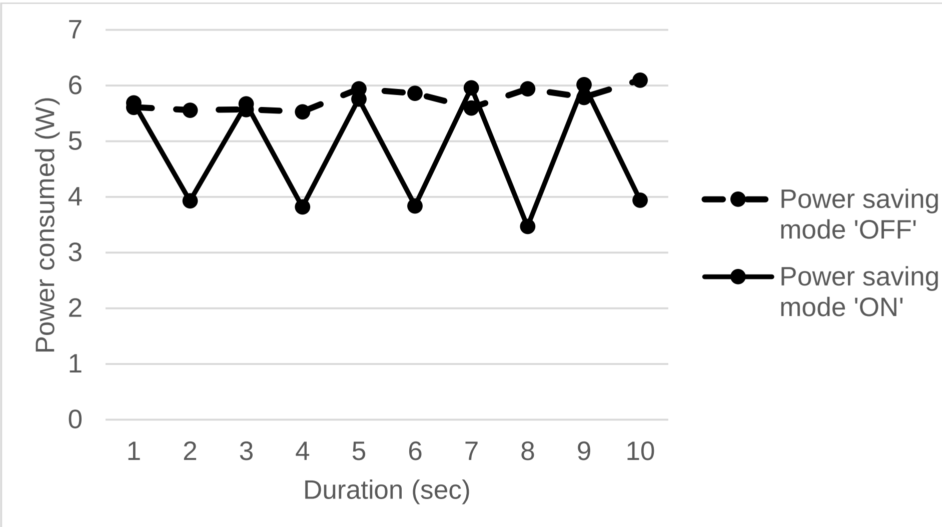

Figure 5: The graph of power reduction for the stepper motor

Figure 6: Autonomous Lake surface cleaning machine

4. Conclusion

The selected DC motor provided adequate torque for effectively accelerating and stopping the autonomous lake surface cleaner. To implement the braking system, dynamic braking was employed, which is a widely used method for DC motors when utilizing an H-bridge motor drive. By installing the ultrasonic sensor, the main objective is to detect the lakeside and prevent collisions. When a signal is received from the sensor, the microcontroller takes charge of regulating the speed of the DC motor using Pulse Width Modulation (PWM). PWM is employed in the case of DC motors to control the speed by modifying the duty cycle of the PWM signal. By adjusting the duty cycle, the effective voltage and motor speed can be controlled effectively. The autonomous lake surface cleaner integrates an energy-efficient enhancement strategy by incorporating an auto power-saving mode. This mode incorporates sleep duration for the stepper motor, allowing the Arduino to enter a low-power state and minimize power consumption effectively.

Acknowledgement

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