Development of an Aquatic Robot for Cleaning Swimming Pools

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***Abstract*— The Innovation of advanced technologies in modern automation has progressively dominating in recent decades. Looking at the research initiatives in this field, there is prevalence in the study and design of robots, substituting workmen, for use in urban environments. Presently, there is an abundance of robots available for sale in the global market with utilizations in residential chores, particularly focused at housekeeping, such as: vacuum based cleaner robots, floor scrubbers, pool cleaners, window cleaners, etc. This type of technology depends on high values and specific features. So the price of these mechanisms is also high, restricting the use of such robots to people with high purchasing power. The objective of the project is to fabricate and design a prototype of an automatic pool cleaner robot that will collect debris and sediment from swimming pools with minimum human intervention. The proposed mechanism will be able to clean each corner of the pool in a defined path with the help of micro-controllers. The rotary brush and suction pump with an integrated filtration unit will serve as the cleaning mechanism. The locomotion system of the project, with the help of grooved wheels and propellers, will be driven by submersible motors. However, the equipment will be kept inside a waterproof casing to prevent damage. In all these activities, CAD plays an important role in visualization and analysis of the robot by means of a model. This model can be used for testing and simulations, assisting decision-making, and avoiding the loss of resources in manufacturing disabled prototypes. All work presented here is part of a larger project that aims to develop newer technologies in urban automation.**

Keywords—locomotion system, microcontrollers, submersible motors, urban automation.

I. INTRODUCTION

Robotics is an interdisciplinary branch of engineering and science that includes computer science, electronics engineering, and mechanical engineering that deals with the conception, design, manufacturing, and operation of robots as well as the necessary computer systems for their control, sensory feedback, and information processing. These technologies are used to develop machines that can substitute human beings and replicate human actions. Manual pool cleaning is usually a repetitive, tiring and tedious task and thus the need for a substitute based on robotic applications becomes necessary. Researchers in artificial intelligence and robotics have made a huge effort, but it is still an open problem because of the unstructured environment of cleaning operations. Today, domestic cleaning robots are seen as exotic appliances or luxury items, at least as far as the Indian home appliance sector is concerned. However, as of now, the pool-cleaning robot appears to be one of the most favoured gadgets, touted to establish itself in the market in the course of the next few years. With the introduction of the pool-cleaning robot in the market, the challenges to clean pools will have been greatly minimized. Physical cleaning of a swimming pool is the process involving human intervention which requires the manual removal of the algae, debris, dirt and other foreign substances present on the pool bottom and its walls. At least 2 or 3 people will be required to clean the pool in an estimated 4 to 5 hours for a standard-sized pool. However, this process will take more time to clean the entire pool, causing downtime and would lead to fatigue; also decreasing the accuracy of the process. In order to maximize the efficiency and quality of cleaning a semi- autonomous system that enables us to combine various aspects of cleaning into a single integrated mechanism having its own control unit is created. Thus, human involvement will be lesser and provide a better solution to the aforementioned problem

Lafaete et al [1] developed a robot that operates autonomously and submerged for cleaning pools. They represent a review of the characteristics of pool cleaning machines, they incorporate suction mechanism using pump and a filter. Floaters are used for traversing the walls of the pool. The pool floor cleaning will demand brushes. The level of planned autonomy will require a few sensors and control devices. Houssam et al [2] presented a survey of different technologies used for underwater cleaning and the available underwater robotics solutions for the locomotion and the adhesion to surfaces. Filippo et al [3] has designed and evaluated a wireless remote control for underwater vehicles in light of the capabilities offered by current optical, RF, and acoustic modem technologies. Chang-Hui et al [4] presented a comprehensive review and analysis of ship hull cleaning technologies. Various cleaning methods and devices applied to underwater cleaning are discussed in detail in this article. The optimization and combination of various technologies in the underwater cleaning robot system researched. Feiyan et al [5] had a design which uses additional thrusters for hull cleaning along with open frame structure type Remotely Operated Vehicle (ROV). This design carries high pay load and has greater degree of freedom in the design of a hull-cleaning ROV such as the positions of the cleaning brushes and metacentre, airtight integrity, maintaining the robot's attitude on the inclined hull surface, and anti-corrosion measures. The main focus in the design of the body is the reduction of body drag to extend the operation period of the cleaning service.

II. ANALYSIS AND DESIGN

The design of this robot primarily involves the analysis of the forces acting on the robot. There are mainly three types of forces act on the robot when it is fully submerged. They are

1. Buoyant Force.
2. Hydrostatic Force.
3. Drag Force.

The weight of the robot and the hydrostatic force together should be more than the buoyant force for the robot to be completely immersed in water. When the robot begins to move in the forward direction on the pool bottom, it begins to experience a resistance force known as "drag force" (DF). The drag force always acts in the direction opposite to the robot's motion that is, the front profile of the robot experiences a force called the "profile drag" and the rest of the body of the robot experience a force called the "skin friction drag". The skin friction drag is directly proportional to the area of the surface in contact with the fluid and increases with the velocity.

Hydrostatic force (Ph) and buoyant force (Pb) are calculated using the following equations.

$$Ph = \rho(water) g\ h\ A \quad (1)$$

$$Fb = \rho(water) g\ V \quad (2)$$

Where ρ is the density of water in kg/m^3, h is the height at which the hydrostatic force is acting on the robot (meter), and g is the gravity (m/s^2), V is the volume of the robot (m^3). It is found that the hydrostatic force = 425 N and buoyant force = 294 N. So the robot will submerge in water.

Calculations of the design parameters are done based on a pool of size length =12.192 m (40 ft.); width= 6.401 m (20 ft.); and a depth =1.52 m (5 ft.). Full-depth pressure for a pool with a depth of 1.52 m (5 ft.) is 1.133 Pa. Therefore, the minimum suction pressure (NPSHR) for a pump will be = 1.16 bar. So, a pump with a capacity of 80 litres/hour (21.1338 US gallons/hour) can be used. A pump with this capacity cleans a volume of 100cm^3 /min. Aassuming that the robot cleans a cube of volume 10 cm x 10 cm x 10 cm in 60 seconds, for optimum cleaning, we consider the robot to be moving at a speed of 0.1 m/s or 10 cm/s.

III. FABRICATION OF ROBOT

PVC pipe structure is adopted for reducing the weight of the robot. Other important parts in the fabrication of robot are Arduino Uno R3 microcontroller, L298-based Arduino motor driver, DC motor, mini submersible waterproof pump, rotary brush and propellers to move.

The Arduino Uno R3 microcontroller operates at 5V. It has a DC current of 40 mA on the input pins and 50 mA on 3.30 pins. The L298-based Arduino motor driver module is a high-power motor driver perfectly suited for driving DC motors and stepper motors. It uses the popular L298 motor driver IC and has the onboard 5V regulator which it can supply to an external circuit. It can control up to four DC motors, or two DC motors with directional and speed control. The L293D DC motor driver module is used to drive the pumps and Brush motors. The same type of DC motor is used for the thrusters (i.e., the propulsion system) as well as for the brush (i.e., the rotary cleaning mechanism). The Robodo Electronics ROBO-1 Johnson 12V geared DC motor for robotics, having a speed of 1000 rpm with a torque of 12 kg-cm is used. A mini submersible waterproof pump is used, having a DC voltage of 12 V and a power consumption of 0.4 W to 1.5 W. The rate of flow is 80-120 LPH with a lift of 1.1 m (3'7.25"). The pump dimensions are 45mm x 24mm x 30mm. The rotary brush is used for cleaning the bed of the swimming pool. The brush's diameter is 40 mm and the material for the bristles is plastic. Propellers are used to move the robot to turn in an angle and thereby help in cleaning the walls of the pool. The propeller diameter is 50 mm. Whereas the motors present on the side of the bot help the bot to move in the front and back direction. The major components used are shown in Fig. 1.

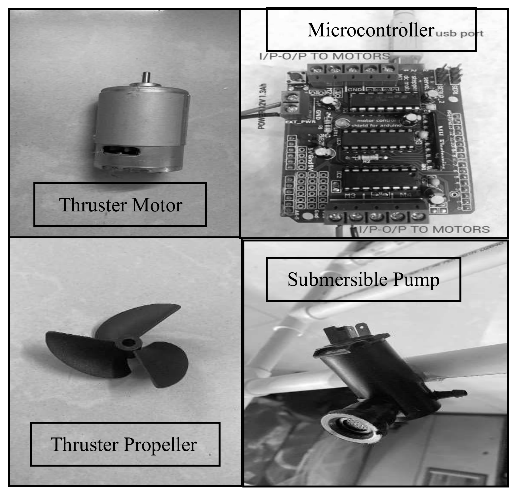

Fig. 1 Major components used

The CAD model of the robot is created using the solid works and is as shown in Fig. 2.

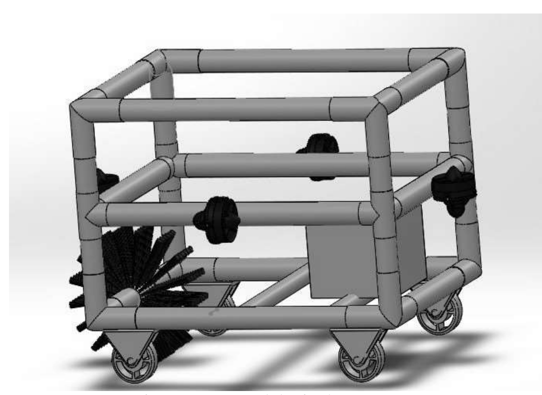

Fig. 2 CAD model of robot

The robot hull composed of 14 hot water pipes made from PVC which form the framework of the robot's hull. They are 25.4 mm (1") thick. To connect all the framework members in the required shapes, 2-way, 3-way and 4-way elbow joints have been used in the midsections and hull corners respectively. Hang ties have been used for affixing the components (particularly the rotary brush and the thrusters) to the pipework hull. The assembled structure of robot is shown in Fig. 3

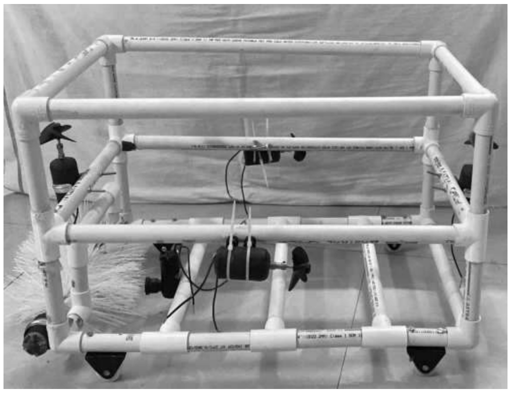

Fig. 3 Assembled structure of robot.

IV. CONTROL OF THE ROBOT

The control unit consists of an Arduino UNO microcontroller coupled with L293d motor driver. It controls four thrusters independently. The L2939N driver drives the pump and rotary brush. The microcontroller uses Pulse-width modulation (PWM) signals for controlling power to the thrusters. It is also capable of reversing direction of thrusters by reversing input power pins. The circuit is powered by a 12-volt battery on board of the robot and control signals are sent to the robot by a 5-meter-long tethered cable running from the laptop to the microcontroller. Fig. 4 shows the circuit diagram for the control unit.

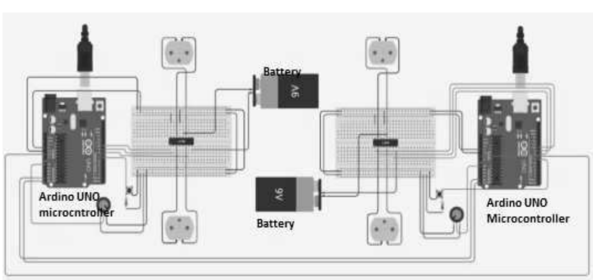

Fig. 4 Circuit diagram of control unit.

V. CLEANING MECHANISM

The cleaning mechanism mainly consists of a brush and a filtration pump. The Fig. 5 shows the assembly of cleaning mechanism. The brush at the front of the robot brushes the floor and gathers up the dust. There is a pump with a 80 liters/hour capacity just behind the brush that sucks in the dirt water which goes through a filter. The clean filtered water is released back into the pool.

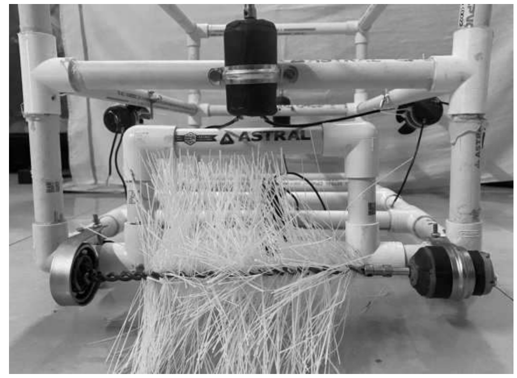

Fig. 5 Robot structure with brush.

VI. TESTING OF ROBOT

In order to observe the required functions of the robot, the robot was first tested on dry land to check all the working functions of the robot, i.e., the working of all its mechanisms. The robot was then immersed in a half-filled pool and the second round of testing was conducted, i.e., the cleaning of the bed of the pool as well as the suction of the dirt/algae and releasing the filtered water back to the pool. This was very basic testing. The testing for the partially immersed robot was also carried out in an acrylic tank which was a replica of the pool. The robot was partially immersed, i.e., about 0.3 m from below the bed. This was done in order to check whether the robot satisfies the primary function of cleaning the bottom of the pool. The testing in dry land and in the swimming pool is carried out successfully.

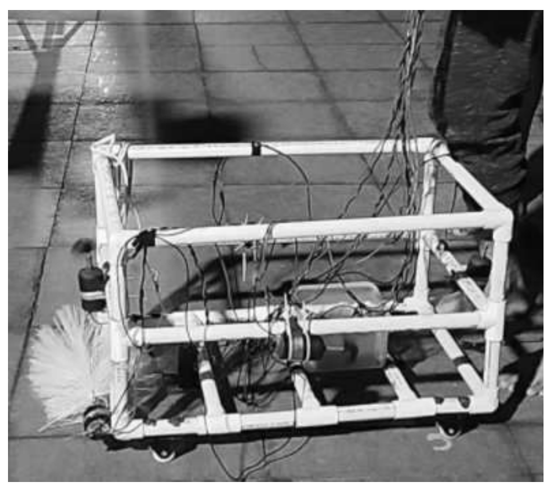

Fig. 6 Robot at dry land Test

VII. RESULT AND CONCLUSION

A wired controlled mechanism was used for a range of 3.048 m (10 feet) around the pool. A powered rotary-brush mechanism is used to clean the pool’s sides and walls. The robot's testing was divided into two phases - the "dry phase" (each subsystem being tested on dry land) and the "wet phase" (testing the complete robot inside the pool). The first part of the testing was carried out in the dry phase. All motors were run at full power and tested for their working. This test yielded good results, in that all four motors ran successfully. The brush and its circuitry were then tested; they were also found to be functioning properly. Unfortunately, while dry-testing the Arduino Uno microcontroller, a grounding failure incurred while connecting the L293D motor driver shield caused both boards to burn out, damaging them irreparably; a DP/DT (Double Pole/Double Throw) switch was used to control the chief functions of the robot, namely the cleaning and locomotion mechanisms.

The wet phase of the testing was done for a partially submerged robot. The robot was immersed to about 0.45 m (1ft 6 in) above the pool bottom. The propellers were activated first, using the DP/DT switch connected to the waterproof circuit box. They were observed to run normally. The powered rotary brush was also observed to be functioning without any glitches. The cleaning was carried out for 5 minutes and the robot could clean a distance of 1.83 m (6 ft) with a speed of 0.1 m/s. The dirt collected in the filter were mainly algae and leftover residues etc., which was cleaned and later reused. The effectiveness of the robot was observed, which was greatly limited by its restriction to floor cleaning and found satisfactory. The estimated time for cleaning the entire swimming pool using this robot was around 60 minutes; a considerable improvement given the time it takes two or three people to manually clean a swimming pool of the same size.

For future development and enhancement of this robot, the number of operations can be increased. Some such possibilities are –

1. Addition of Game Pad: A gamepad can be used as its primary control system, as the game pad makes it easier for the handler for operation rather that the requirement of prior knowledge for controlling via a laptop or PC. The gamepad makes the robot easier to control.

2. Acoustic Control Mechanism: Taking it a step further, an extensive study was done for the project on acoustic controls for the robot. Acoustic control methods can also be developed; the waterproofing requirements decrease and so, the robot can be controlled from a greater distance.

3. Optimization of Controls: The number of major operations can be increased as well. Addition of compatible accessories, such as cameras, probes, sampling tubes, and temperature sensors will advance the operations of the robot so as to optimize its functions and increase its efficiency.

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