# Aquatic multi-robot system for lake cleaning

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# AQUATIC MULTI-ROBOT SYSTEM FOR LAKE CLEANING

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*Abstract*— **This paper discusses the design of a multi-robot system of autonomous aquatic vehicles that can be used for cleaning of lakes and maintenance of fisheries. The traditional method of removing the weeds manually and collecting them along with other surface wastes is highly inefficient and labour intensive. Aimed at automating the entire process, the robots make use of tactile sensors and wireless communication to traverse autonomously and collectively perform cleaning operations such as removing the surface impurities, pumping oxygen into the water, spraying chemicals and distributing food at appropriate locations along with measuring the water quality. A novel algorithm for navigation and waste removal strategy of the multi-robot aquatic system, inspired by insects such as ants and bees, referred to as 'recruitment algorithm', has been proposed. Through the help of virtual simulation, supplemented by real environment testing, it has been demonstrated that by the use of a multi-robot systemwith this strategy, an effective and rapid cleaning is feasible.**

## 1. Introduction

The condition of the lakes and ponds in majority of the developing countries are abysmal. A lot of money and efforts are being spent by the government and private firms on cleaning and maintaining them at regular intervals [1, 2]. This work aims at developing a multi-robot system of autonomous aquatic vehicles, which can perform various tasks required for the cleaning and maintenance of lakes, ponds and fisheries along with performing secondary functions such as controlled food distribution and fishing.

A few aquatic robots have been built earlier for the purpose of surface cleaning [3, 4]. These works, however, are limited to a few functions only and based on a single robot system. A few works are available in the open literature, which have discussed about the development of such special purpose robot [5, 6].

This work aims at developing a more versatile and efficient system by the usage of multiple robots. Activities like removing algae, leaves and twigs, spraying of chemicals at the appropriate locations, pumping oxygen whenever required, checking the water quality as well as deploying payload are planned to be done autonomously. This may save a lot of human effort and provide a sustainable solution to the pervasive problem.

For the purpose of navigation and trash cleaning on the ground, many well-designed algorithms have been developed earlier for both single robotic systems as well as for swarms [7, 8]. However, because of the difference in the dynamic environment, propulsion system, and the difficulty to accurately determine the current position based on relative velocity and acceleration, these algorithms cannot be directly used on aquatic surfaces. Also, the navigation algorithms developed earlier for autonomous aquatic robots have not been designed with cleaning as an integral part of them [9]. Thus, there is a need for developing a new algorithm for the navigation of these robots and optimizing the effort in waste removal. This paper addresses the issue and presents a viable solution.

## 2. System/RobotDesign

The four important issues for designing the aquatic robots are: cost effective solution along with robustness, efficacy and durability. Due to the nature of the cleaning work, the vehicle structure is designed such that it can provide high stability, great maneuverability and can easily collect all the waste flowing in between. A pontoon shaped hull works best for this case and fulfills all the hydrostatic, sea-keeping and structural stability criteria [10]. For the purpose of removal and collection of surface waste, a motor driven track-belt system has been designed that can collect the wastes in a section covered with a net. This design provides a simple and effective waste removal and accommodates large amounts of waste within a small space. Moreover, as the collected waste floats on the water surface, the robot does not need to support its weight. The lower section of the belt is placed below the water level to easily take out the floating weeds.

For the prototype (Fig. 1), the hulls were made up of two long PVC pipes supported together with the help of an aluminuim truss. This light and tough structure supports the total weight of the system. The design parameters of this prototype are given in Table 1.
To navigate autonomously in small and constrained spaces, a propulsion system that can provide high mobility and short turning radiusis required. Due to its flat front and the central waste collection system, the robot is also required to overcome high form and skin drag given by:

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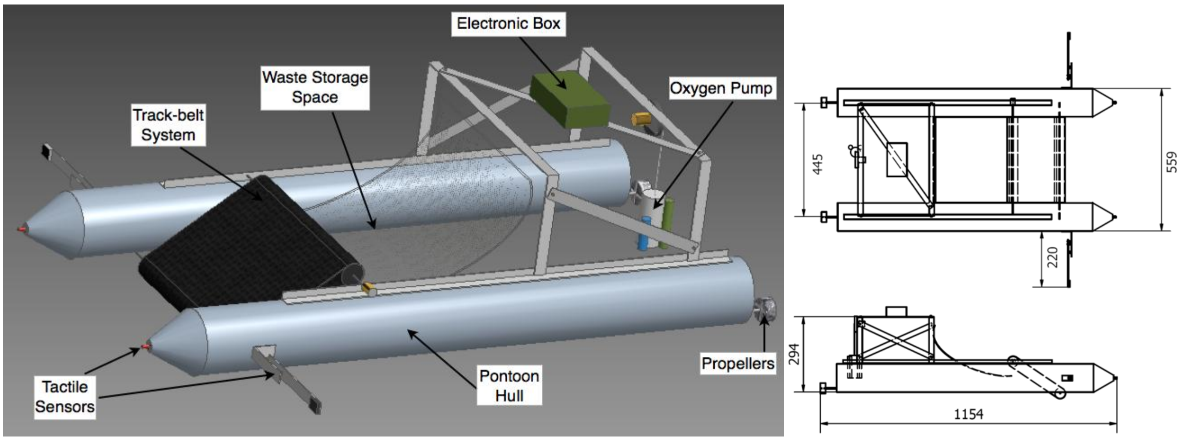


Figure 1. Structure of the robots used for lake cleaning

$$Drag = -(18\, v^2 + 0.027\, m\, v^{1.61})$$

Where, $v$ is the velocity or the robot in m/sec,$m$ is the total massor the robotin kg and Drag is in Newtons.

Thus, a propulsion system based on a differential drive mechanism has been designed, whish allows the robots to take a 360$^{\cdot}$ turn on the spot and provides high thrust. Placing the drive motors inside the hull, protects them from water seeping inside its casing.

As the robots are designed to traverse autonomously, they need to sense when they get close to an obstacle or the boundary of the lake. Majority of the sensors such as the ultrasonic sensors, sharp sensors, image processing, laser scanners, depth ranging, tactile sensors etc. that work well on land are either unusable in water bodies or are unable to differentiate between hard rocks and leaves. Tactile sensors form a very good alternative due to their simple design, low cost and their ability to differentiate the collectable wastes from the rigid ones. Measuring the water quality of a lake/fishery is also very important in order to determine where to pump oxygen, detecting regions of contamination and in checking the dissolved salt content, which are essential for the survival of aquatic life [11]. In the current prototype, two tactile sensors were mounted directly onto the nose of the vehicle to detect any obstruction from the front. For the side sensors, a lever mechanism has ben used, placing the tactile switch at the lever and connecting one of the ends to a fixed support. IR LEDs and photo-resistors are used to get a measure of the total suspended particles in the water.

The robots are primarily designed to work autonomously in groups, but it is also important for them to be remotely controllable whenever the operator wants them to clean up a particular region of a lake or to bring them back to a desired location.The control system thus designed can be toggled between autonomous and manual mode by a remote.The inputs from all the sensors and the wireless receivers are fed intothe microcontroller, which processes the information and sends the desired commands to motor drivers for propulsion, waste collection and payload deployment.

TABLE I. SPECIFICATIONS OF THE ROBOT

| Design Parameter | Value |
|---|---|
| Overall Dimensions | 1154mm X 559mm X 294mm |
| Net Weight without playload | 12 kg |
| Maximum weighwith playload | 18 kg |
| Area coverage per hour | 760 $m^2$ |
| Maximum speed at full loading | 0.38 m/sec |
| Maximum forward thrust | 3.6 N |
| Waste removal capacity per run | 7875$cm^3$ |
| Average battery backup while cleaning | 2 hours |
| Control System | Autonomous + Manual |
| Drive motors | 750 rpm 1.2N-m torque |
| Water quality sensors | QRD Photoresistive diode + IR LED |
| Wirelss module | 8 channel Radio Frequency PS2 transmitter – receiver |

## 3. Navigation Algorithm

Some of the salient features of the navigation algorithm for the multi-robot system and the recruitment strategy are discussed below.

The area around a robot has been divided into four regions, separated by radii, Rc (Critical radius), Rw (Working Radius) and Ro(Outer Radius). If another robot or the lake's boundary comes inside the, Rc of a robot, obstacle avoidance algorithm comes into act. While cleaning a region, if a robot detects waste in its path for 5 consecutive seconds, it starts to follow a spiral path in order to collect maximum waste in that region and goes back to a straight-line path if no more waste is detected. In order to achieve the desired spiral path, the 8-bit Pulse Width Modulation (PWM), which controls the motor voltage, is actuated as follows:

PWM-right propeller = 255 ; PWM-left propeller = 255*(1-$e^{-at}$)

Here, the value of 'a' controls the distance between successive turnings.

### *3.1. Recruitment Algoritm*

A 'Recruitment call' is a wireless signal that a robot sends to all other robots if it finds enough waste in a particular region and wants the other 'free' robots to clean up that particular region. This method of giving recruitment calls has been inspired by insects such as bees and ants [12, 13].

While collecting waste, the robot's trackbelt torque increases, causing a surge in the input current flowing through the motor. This is used to detect whether the robot is collecting waste at that instant.

The algorithms for sending and receiving the recruitment calls have been demonstrated by the help of a pseudo-code below.

```
/*Sending Recruitment calls*/
if waste is equal to 0{
time_waste_colected = 0;
follow a straight path;
set mode to 'free';
}
if waste > 0{
set mode to 'busy';
time_waste_colected = time_waste_colection + 1;
if time_waste_colected > 5 seconds{
send recruitment calls;
execute spiral path;
}
}

/*Receiving Recruitment calls*/
receive recruitment calls from robots B1, B2.....Bn
ifmode = 'free'{
find the closest robot and set it as B0;
if distance from B0 is between Rw and Ro
approach robot B0 for 1 time-step;
}
```

Only the robots between Rwand Rofrom the robot giving recruitment calls respond to it asa robot beyond Ro will it will take a long time to reach and will waste unnecessary energy in getting there. The robots within Rcand Rware already in close proximity to the robot sending the recruitment calls and thus ignore them.After coming within Rw of the robot giving recruitment calls, the robot starts to follow random paths around it, trying to look for waste.

While approaching the robot which gave the call, if a robot finds enough waste on the way, it goes into the 'busy mode' and ignores the recruitment calls.

## 4. Simulation

To test the effectiveness and efficiency of the multi-robot system, we carried out the simulations of a 3-robot system in a lake like environment for varying lake sizes and random waste distribution. The robots were mathematically modeled as rectangular bodies and the total force (drag and viscous) was calculated as a function of its linear velocity, angular velocity and the amount of waste collected. The simulationswere carried out in C++ using the Enki robotic library and Physics engine, which provided us with the positions and angles of the robots at different instances of time. These position and angles obtained were then used to generate the real-time simulation in MATLAB. The snapshots of a simulation at the beginning and after 2 hoursare shown in Fig. 3. The robots, modeled as rectangular bodies, are shown in blue. The green points represent the waste to be removed and the brown region represents a part of the lake's boundary. As the robot passes over a waste, it is assumed to be removed.

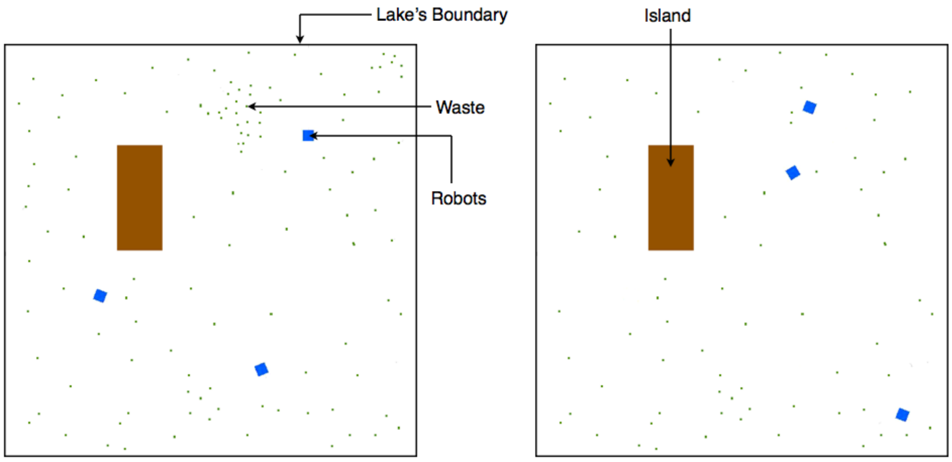


Figure 2. Snapshot of the waste distributionat (a) the start and (b)after 2hours

## 5. Results and Conclusion

This paper has proposedthe design of a multi-robot system of autonomous aquatic vehiclesto be used for lake cleaning. For the purpose to navigation, a novel recruitment algorithm has been developed and simulated for a 3-robot system in a lake like environment.As therobots have been designed primarily to be used in developing countries, their cost have been kept below US$ 350 to be economically feasible.

The testing of a single robot prototypein a controlled pond proved to be effective in waste removal, payload deployment and water quality sensing. Some of the results from its testing are given in Table 1. Though the boats did not have a very high speed, they produced a great amount of thrust, which was needed to overcomea large amount of drag acting on the system. These robots have been designed in such a way that they require the least amount of maintenance and human interference, doing most of their work autonomously, but at the same time, having the option to be controlled manually. After the collection area is full, the robots need to go back to a defined region on the lake's boundary and dump the waste on the ground.

The simulations performed for a 3-robot system with the recruitment algorithm concluded to be successful in removing a minimum of 80% of the randomly distributed wastefrom a 65,000$m^2$lake in a single day. For the simulation shown in Fig 3, though the robots covered just 8% area of the22,300$m^2$ lake within 2hours, theyremoved 21% of the total waste, demonstrating the effectiveness of the recruitment strategy.Ifall the robots have to come back to the same point for dumping the waste and recharging their batteries,an increase in the number of robots would not lead to a significant increase in the cleaning area,aseach robot onlycover a small regionaround that point. Also, the lakesshould have a minimum dimension of 100m X 100m for these robots to be useful and effective.

Apart from the cleaning activities, these robots can also be programmed to perform many other useful functions, such as fishing in a lake. A pair of robots can be used to travel in co-ordination with a hooked net in between, trapping the fishes in the middle.

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