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A Floating Waste Scooper Robot On Water Surface

Niramon Ruangpayoongsak*, Jakkrit Sumroengrit, Monthian Leanglum
Production Engineering Department, Faculty of Engineering
King Mongkut's University of Technology North Bangkok, Thailand (niramon.r@eng.kmutnb.ac.th)

Abstract: In developing countries, cleaning water surface is a routine task. Collecting large amount of dry waste floating such as plastic bottles confronts with tension on water surface and small drag force causes waste floating away. The aim of this research is to design a robot that replaces human force for floating waste scooping and investigate performance of the designed waste scoopers installed on the Floating Waste Scooper Robot. The robot mechanism design, waste scoopers, and control are presented. The robot has been successfully tested on calm water surface. Experiments were conducted on a pond and results show influence of varying the robot driving speed and conveyor belt speed on waste scooping. The capability of the different designed scoopers is evaluated and weight of plastic bottles collected by human using scoop net is also compared with that of the robot.

Keywords: Dry Waste, Robot, Scooper, Water Surface Cleaning.

1. INTRODUCTION

In developing countries, growing amount of dry waste in canals, ponds, and lakes affect water drainage and life quality of residents living closed to those areas. Often found floating waste is such as plastic scraps, foams, tree leaves, and aluminum bottles. Accumulating of the dry waste floating on water surface can obstruct water drainage in city canals and cause floods. Water surface cleaning must therefore be done regularly.

Due to less specific weight than water, the dry waste such as foams or plastic bottles can be easily observable on water surface. As the waste has small drag force and water surface tension causes surface wave, the waste usually flows away when reaching by ship or boat. The typical waste collecting by human is often done by using scoop net with long handle. However, the operation requires much effort of cleaning team when amount of waste is enormous.

Unmanned surface vehicle has been developed since 1993 for various missions such as testing of navigation and control systems, ocean exploration, fish tracking, or military applications [1]. The vehicle platforms were often made of pontoon or kayak with propeller and rudder. Similar structure has been expanded on lake surface cleaning ship where flight conveyor is mounted in the front for collecting garbage or rubbish.

As for water surface cleaning, previous works focused on robot maneuvering control and autonomous motion control using hydrodynamic model [2-3]. A chain conveyor belt was mounted between pontoons for collecting rubbish. The maximum driving speed was at 1 m/s and the conveyor belt speed was about 0.2 m/s [4]. In parallel, an autonomous ship for garbage cleaning around bank of a lake was proposed [5]. A flight conveyor belt was rubber with holes and aluminum fins were zig-zag shape. Later, an autonomous aquatic multi-robot system for lake cleaning was presented [6]. A track belt system was used for removing weeds. The maximum driving speed at full load was 0.38 m/s and simulation approximating for amount of collected waste in large area was proposed.

In previous works, the pontoon was often selected since it can reduce surface wave generated when reaching the waste and different kind of belt system was selected depending on type of waste to be collected. The capability of waste collecting was evaluated in the simulation whereas the robot speed and the conveyor belt speed were kept constant.

In this work, we focus on collecting plastic bottles floating on water surface. The main contribution is as follows: First, it is a challenge to collect round shape and slippery plastic bottles which usually flow away from the robot due to drag force. Second, the capability of waste collecting is measured by practical experiments conducted on a pond where the robot is tele-operated control. Third, this work presents a study of influence of the robot driving speed corresponding with conveyor belt speed on waste collecting. The same speed as in previous works is also implemented.

This paper presents the Floating Waste Scooper Robot (FWSR) having two different designs of waste scooper. The structure of the robot and mechanisms as well as control is explained. Waste collecting is investigated such as when activating only one scooper or both of them or when varying the conveyor belt speeds as well as the robot driving speeds. The amount of collected waste by the robot is also compared with human capability using a scoop net.

The organization of this paper is as follows: First, the mechanism of the FWSR is introduced. Next, the waste scooper design and the robot control are explained. After that the experimental results and analysis are presented. Finally, conclusion is given.

2. FLOATING WASTE SCOOPER ROBOT

The FWSR is designed and developed for replacing labor cleaning waste on city canal, lake, pond or pool. The robot is a ship made of two pontoons fixing

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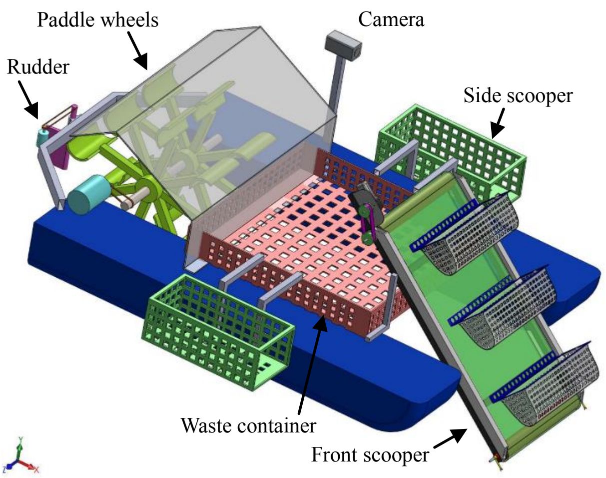
together leaving free space in the middle for the front scooper, waste container, and paddle wheels as shown in Figs. 1a and 1b. From our experience, green plastic net is better than rubber belt since it is lighter and generates smaller amplitude of surface wave.

2.1 Driving and steering mechanism

Double paddle wheels and a rudder were selected for driving speed and direction control mechanism as shown in Fig. 2. The paddle wheels are mounted next to each other on the same shaft between the pontoons whereas the rudder is mounted behind the paddle wheels.

The paddle wheels are driven by a 250W 400 rpm DC brushless motor. Driving speed of the robot is adjustable in both forward and backward direction by rotating speed of the paddle wheels. When approaching waste, the paddle wheels turn at low speed in order to reduce generated wave that causes waste flowing away.

The rudder is a simple rectangular aluminum plate and rudder angle is adjustable for maneuvering control. Turning left and right is controlled by adjusting angle of the rudder with respect to the robot body. The rudder is driven by a stepping motor with gearbox.



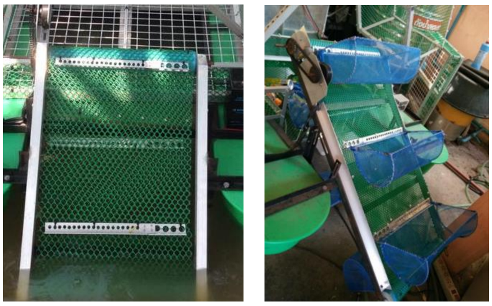
(a) 3D model

(b) Photograph

Fig. 1 The Floating Waste Scooper Robot

(a) Paddle wheels (b) Rudder

Fig. 2 The driving mechanism



(a) Old (b) New

Fig. 3 The front scooper

Fig. 4 Experiment

Table 1 Comparison of the designed waste scoopers.

No.	Scooper	Mechanism	Storage shape	Material
1	Front	Flight conveyor	Half-cylinder	Nylon-net
2	Side	Lifting Arm	Rectangular box	Plastic net

2.2 Waste scoopers

Two types of mechanism are used for waste collecting: One is a flight conveyor and the other is a scooping arm with basket. The flight conveyor is often used in the literature whereas the scooping arm is a one DOF robot arm. Both of them can overcome water surface tension as material is net. Differences among them are compared in Table 1. The mechanisms and storage shape are significantly differentiable.

- The front scooper was developed in [9]. The old design of the front scooper is as shown in Fig. 3a. The fin shape was bar shape and it was almost impossible to scoop up plastic bottles on water surface. Later, problems were analyzed and a new design is selected to be half cylindrical shape made of nylon-net as shown in Fig. 3b. The nylon-net has light weight and also increases dynamic of the fin. Cylindrical shape increases storing space on each fin. The flight conveyor is driven by a 12 V 110 rpm gear motor. When the robot reaches floating waste, the flight conveyor rotates and scoops up waste in the front then release in waste container located between the pontoons. Conveyor belt is made of plastic net minimizing surface wave when the robot moves and the belt speed is adjustable.

- The side scoopers are made of plastic net as a rectangular basket fixed on the arm on the left and on the right side of the robot as shown in Fig. 1 and 4. The basket is front-opened. Half of the basket is underwater at the initial position enabling waste to flow into the front-opened end of the basket. The arm is driven by a gear motor. When the arm is lifted up to the top, scooped waste will fall down into the waste container.

2.3 Electronics system

The diagram of the electronic circuit is shown in Fig. 5. The robot is controlled by Arduino Uno and Arduino Mega 2560. An operator can manually control the robot by sending joystick or keyboard command from laptop through wireless LAN, access point, and Arduino Uno attached to Ethernet shield. The format of data transmission and robot motion control contains characters similar to [7] where the robot can go forward, go backward, turn left and turn right. In addition, the driving speed is adjustable in real time.

The control command is transferred from Arduino Uno via Arduino Mega 2560 to the motor drivers of the front scooper, the side scooper, the pan/tilt laser, the rudder, and the paddle wheels. In the opposite direction, the sensor data is acquired from GPS, IMU, laser, tilt sensor, and encoders back to the laptop. The GPS, IMU, and tilt sensor are used for robot tracking. The laser is a digital distance meter used for detecting floating waste on water surface. The encoders are used for the driving speed control, the conveyor belt speed control, and the lifting arm speed control. A camera is mounted on the robot for VDO acquisition during navigation and tele-operated control.

3. ROBOT CONTROL

3.1 Tele-operated control

As in [8], the wireless network between the on-board computer and laptop must be established at the beginning. After that the robot waits for command from the control program on the laptop. If joystick or keyboard command is obtained, the data is first checked and then sent to the Arduino. The graphic user interface is developed as shown in Fig. 6. There are tabs for keyboard, joystick, and Ethernet. On the keyboard tab as in the figure, the keyboard control commands are listed on the left and the VDO is displayed on the right hand side for long distance robot control whereas operator is sitting on ground. The robot driving speed is manually adjustable on a horizontal slide bar.

3.2 Speed control

PID controller is capable for driving speed, conveyor belt speed of the front scooper, and arm lifting speed of the side scooper. The input/output relationship for the PID controller [10] is

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \tag{1}$$

Where $u(t)$ is the control action. K_p, K_i, K_d are proportional, integral, and derivative gain and $e(t)$ is error signal. The control action is a sum of proportional term, integral term, and derivative term. The PID controllers are implemented on Arduino taking encoder signal as feedback signal for speed measurement.

It is supposed that the driving speed and the belt speed have effect on the waste collecting. Therefore, the influence of the robot driving speed and the conveyor belt speed of the front scooper on the waste collecting is studied.

- The driving speed is the speed of the robot on water surface varied by PWM. Three driving speeds are selected as slow, medium, and fast at 0.125, 0.21, and 0.38 m/s, respectively. The maximum driving speed at 0.38 m/s is also used in [6]. Furthermore, we found that the driving speed of 1 m/s as in [4] is too fast for collecting waste on our robot.
- The front scooper is controlled by turning the conveyor belt with appropriate speed so that the fins scoop up floating waste in the front of the robot. Two belt speeds are selected as slow and fast at 0.2 m/s and 0.5 m/s, respectively. The 0.2 m/s speed is also used in [4].
- Both arms of the side scooper are lifted simultaneously at 12 times per minute.

4. EXPERIMENTAL RESULTS

The experiments are divided into two parts. One is testing of water surface cleaning by using a scoop net as shown in Fig. 7. The other is cleaning by using the FWSR with variation of the driving speed of the robot and the belt speed of the flight conveyor. The capability is evaluated by weighting amount of plastic bottles collected within one minute in a 3x3 square meters closed area.

4.1 Human using scoop net

Due to fatigue, human force is lower when duration of time is longer. The time duration is therefore set to one minute for the best capability of human force. Table 2 shows the experimental results of waste collecting by using a 30 cm diameter scoop net. The age, height, and weight of three young men are listed. The experiment is repeated 3 times and average weight of collected bottles is calculated. The men are 24-28 years old, 164-173 cm tall, and have 64-76 kg weight. They can pick up 0.857-1.128 kg of bottles. The overall average amount of waste collected is 0.975 kg.

4.2 Robot using the waste scoopers

The test environment is shown in Fig. 8 and 9. The robot starts at 7 meters in the front of the area closed by bamboos so that plastic bottles cannot flow away. The amount of plastic bottles collected within one minute by FWSR is recorded.

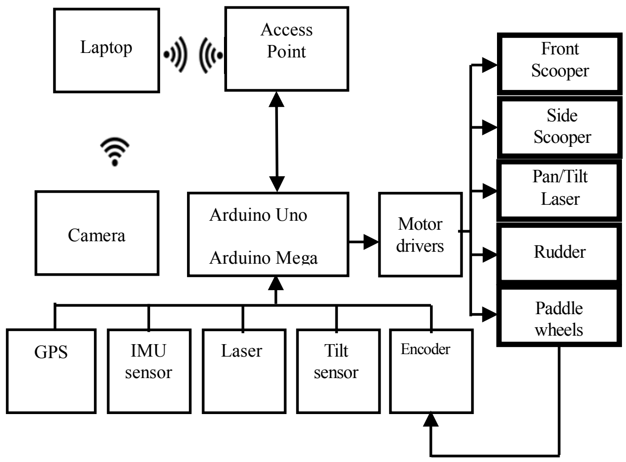


Fig.5 Electronics system diagram

Fig 6. Graphic User Interface

Fig. 7 Water surface cleaning by using scoop net

Table 2 Result of waste collecting by using scoop net

No.	Age	Height (cm)	Weight (kg)	Collected waste (kg)	Average (kg)
1	24	173	75	0.76 0.97 0.82	0.857
2	27	164	76	0.74 1.115 0.93	0.928
3	28	167	64	1.205 1.01 1.17	1.128
Overall average amount of waste collected					0.975

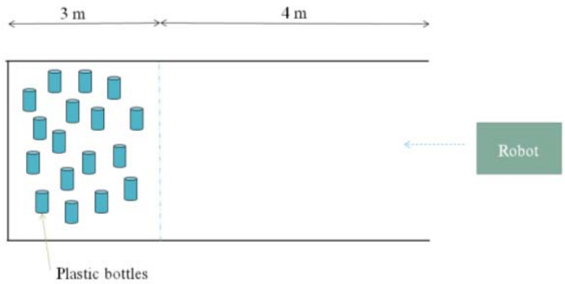


Fig. 8 Schematic diagram of test environment

Fig. 9 Test environment

1) Comparison between the front and the side scoopers

Scooper activation is divided into two cases. The first case is when only the front scooper is activated and the latter case is when both the front and the side scooper are activated. Weight of collected waste from three trials is recorded and average weight is calculated.

Table 3 shows amount of waste collected when only the front scooper is activated. For test no. 1, the belt speed is slow at 0.2 m/s and the robot speed is slow at 0.125 m/s, the weight of collected plastic bottles of 3 trials are 0.715, 0.890, and 0.835, respectively. The average weight of collected waste is 0.810 kg. For test no. 2, with slow conveyor speed and medium driving speed at 0.210 m/s, the average weight of waste is 1.248 kg. For test no. 3, with slow conveyor speed and fast driving speed at 0.38 m/s, the weight of waste is 0.810 kg. From test result no. 1-3, the results show that driving the robot faster cannot always increase amount of collected waste.

For test no. 4 in Table 3, the belt speed is set to 0.5 m/s or fast and the robot speed is set to slow, the average weight of scooped waste is 0.183 kg which is the minimum. For test no. 5 and 6, the driving speed is medium and fast and the average weight of waste are 1.005, and 1.252, respectively. From test result no. 4-6, at fast conveyor speed, more waste is scooped when robot driving speed is higher.

In Table 4, the same set of speed values are chosen as in Table 3. For test no. 1 in Table 4 (the side scooper is also activated), at slow conveyor belt speed and slow robot driving speed, weight of waste are 1.225, 1.055, and 1.260 kg resulting in average of 1.180 kg. By comparing results of test no. 1 in Tables 3 and 4, only 0.37 kg extra bottles are gained when the side scooper is also activated. Through result of test no. 2-6, the extra weight gained in Table 4 shows the same trend in that activating both scoopers yield higher amount of scooped waste and the side scooper has less capability than the front scooper.

Table 3 Result of waste collecting when activating only the front scooper

No.	Conveyor speed (m/s)	Driving speed (m/s)	Collected waste (kg)	Average (kg)
1	0.2	0.125	0.715 0.890 0.835	0.810
2	0.2	0.210	1.080 1.410 1.255	1.248
3	0.2	0.380	1.070 0.825 0.535	0.810
4	0.5	0.125	0.210 0.080 0.260	0.183
5	0.5	0.210	1.070 1.195 0.730	1.005
6	0.5	0.380	1.485 1.095 1.175	1.252

Table 4 Result of waste collecting when activating both scoopers

No.	Conveyor speed (m/s)	Driving speed (m/s)	Collected waste (kg)	Average (kg)
1	0.2	0.125	1.225 1.055 1.260	1.180
2	0.2	0.210	1.530 1.565 1.630	1.575
3	0.2	0.380	1.665 1.035 1.356	1.352
4	0.5	0.125	1.365 1.025 1.220	1.204
5	0.5	0.210	1.520 1.780 1.540	1.613
6	0.5	0.380	1.595 1.705 1.830	1.710

The result of activating only the front scooper and activating both scoopers are compared in Fig. 10 showing average weight of waste when varying the robot speed at 0.125, 0.210, and 0.38 m/s and fixing the belt speed slow. At 0.210 m/s or medium driving speed, the robot can collect more waste than at 0.125 m/s or slow driving speed. In contrast, when the driving speed is fast at 0.380 m/s, the robot can collect less amount of waste than at medium speed since when the robot drives at the maximum speed, the scooper is too slow for picking up plastic bottles before drag force pushes them away. The maximum capability at slow belt speed is achieved when the driving speed is medium.

In Fig. 11, the belt speed is set to fast and the driving speed is varied. At slow driving speed, the scoopers capability is low since the flight conveyor belt of the front scooper rotates too fast causing large amplitude of wave and more plastic bottles flow away. Drag force pushes waste floating away before scoop them up. At faster driving speed, more bottles are scooped. Here, the performance of the front scooper increases with the driving speed. The maximum capability at fast belt speed is achieved when the driving speed is fast.

2) The best performance for waste collection

As shown in Fig. 12, effect of belt speed on the front scooper is quite significant at fast driving speed. In the figure, fast conveyor belt speed has higher capability than at slow belt speed. At fast belt speed, amount of collected plastic bottles is 1.71 kg. On the other hand, at slow belt speed, amount of collected waste is only 1.352 kg. This indicates that the faster belt speed creates quicker motion of fin on the front scooper and it complies with the fast driving speed resulting in the maximum amount of waste collected. Therefore, the appropriate belt speed is 0.5 m/s and the driving speed is 0.38 m/s. In contrast with [4], the appropriate belt speed in our work is found to be faster than the robot driving speed.

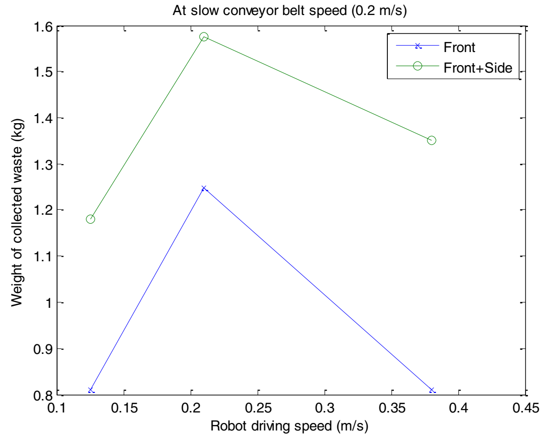


Fig. 10 Amount of collected waste (kg) at slow (0.2 m/s) belt speed and different driving speeds

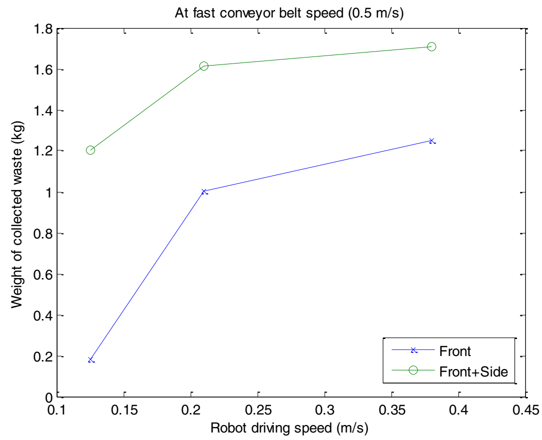


Fig. 11 Amount of collected waste (kg) at fast (0.5 m/s) belt speed and different driving speeds

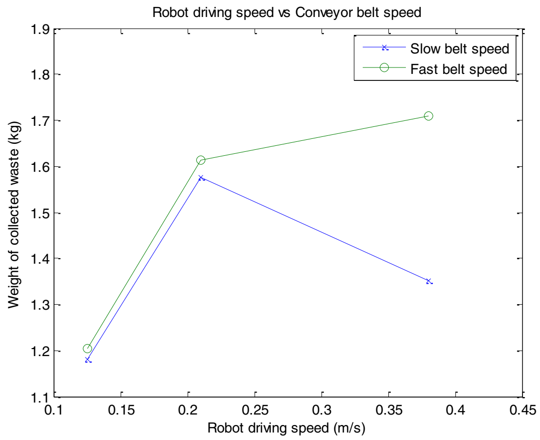


Fig. 12 Amount of collected waste (kg) when both scoopers are activated.

5. CONCLUSION

The structure of the Floating Waste Scooper Robot is presented in details. Both scoopers are made of plastic net and cause small surface wave amplitude when compared with rubber. Difference in term of mechanism has much influence on scooping the floating plastic bottles. Capability of the designed waste scoopers was successfully evaluated. The front scooper has better capability than the side scooper. It is also shown that both the robot driving speed and the conveyor belt speed has influence on waste scooping and the best capability of the robot is achieved at 0.38 m/s driving speed and 0.5 m/s belt speed. The maximum amount of collected bottles is 1.71 kg/minute, which is 75% over that of human force using a scoop net. Therefore, the FWSR is proven to be capable to replace labor for water surface cleaning.

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