SUGISAKA MASANORI

Journal of Robotics, Networking and Artificial Life
Vol. 9(3); December (2022), pp. 209–215
ISSN (Online):2352-6386; ISSN (Print):2405-9021
https://alife-robotics.org/jrnal.html

Research Article

Design and Development of Ocean Debris Collecting Unmanned Surface Vehicle and Performance Evaluation of Collecting Device in Tank

Jonghyun Ahn[1], Shunsuke Oda[2], Shota Chikushi[3], Takashi Sonoda[4], Shinsuke Yasukawa[2]

[1]*Dept. of Intelligent Mechanical Engineering, Hiroshima Institute of Technology, 2-1-1 Miyake,Saeki-ku, Hiroshima, 731-5193, Japan*
[2]*Dept. of Human Intelligence Systems, Kyushu Institute of Technology,2-4 Hibikino, Wakamatsu, Kitakyushu, Fukuoka, 808-0196, Japan*
[3]*Dept. of Robotics, Kindai University, 1 Takaya Umenobe, Hiroshima, 739-2116, Japan*
[4]*Dept. of Engineering, Nishinippon Institute of Technology, 2-11, Aratsu, Kanda-town, Miyako-gun, Fukuoka 800-0396, Japan*

ARTICLE INFO

Article History
Received 28 April 2022
Accepted 02 August 2022

Keywords
Ocean debris
Ocean cleaning robot
Marine robotics
USV design

ABSTRACT

In recent years, the oceans debris is increased because of human's activity. Especially, the plastic debris, such as plastic bottles, is not biodegradable, and therefore those are creating serious environmental problems. The ocean debris collecting in the world is done through volunteer activities. However, these activities require a lot of time and labor. In this research, we proposed a method of ocean debris collecting USV operation method. Also, we designed and developed a USV (Unmanned Surface Vehicle) for the purpose of autonomous oceans debris collecting mission and evaluated the developed ocean debris collecting device. In the development of USV, electronic parts, which are to operate the mission autonomously, were selected. Then, each electronic part was placed inside the waterproof box according to the designed power and communication system diagram. In the development of oceans debris collecting device, we designed a belt conveyor type device. A motor was selected to rotate the device and a decelerator, which used the planetary gear mechanism, was designed. To evaluate the performance of the developed ocean debris collecting device, we tested various types of plastic bottles in tank environment. As a result of the experiment, the developed USV collected various types of plastic bottles with a 47.7% probability.

© 2022 *The Author*. Published by Sugisaka Masanori at ALife Robotics Corporation Ltd
This is an open access article distributed under the CC BY-NC 4.0 license
(http://creativecommons.org/licenses/by-nc/4.0/)

1. Introduction

In recent years, the increase in ocean debris cause serious problems such as damage to marine ecosystems, damage to marine tourism industry, fisheries, and biodiversity loss. Especially, the ocean plastic wastes, such as plastic bottles, cannot be naturally decomposed, so it continues to increase worldwide as ocean plastic debris [1], [2], [3], [4]. To reduce of these damages, many volunteers and workers clean the coastal area [5], [6], [7]. However, this cleanup method is required a lot of cost such as financial cost, time, and manpower. Recently, marine robotics system can be mentioned as a solution to this situation because the USV (Unmanned Surface Vehicle) can easily approach ocean plastic debris and work over a large ocean area for a long time [8], [9], [10].

Corresponding author's E-mail: j.ahn.h2@it-hiroshima.ac.jp : https://www.it-hiroshima.ac.jp/english/

In this paper, we designed and developed a USV, which is called MIROCA (Maritime Intelligence Robot for Ocean Cleaning Assistance), to collect ocean plastic debris autonomously. Also, we evaluated the developed ocean debris collection performance by the experiment, which employed various types of plastic bottles, in the tank environment.

2. Development of Ocean Debris Collecting USV

We propose a method to collect oceans debris using USV and UAV (Unmanned Aerial Vehicle) in Fig.1.

As shown in Fig.1, the proposed operation method is composed 6 steps. In the first step, the UAV patrols the set ocean area while take GPS data and ocean surface images which include ocean debris. The UAV send GPS data and ocean surface images to computer at USV base in the second step. In the third step, the computer uses the sent data to calculate information, such as the location, type, size and number of the ocean debris, and then the information is sent to USV. The USV moves to the debris location, and then USV collects the ocean debris in the fourth step. In the fifth step, the USV moves to next the debris location and collects the ocean debris when the fourth step is completed. In the final step, when the USV has collected all the ocean debris in the photographed ocean area by UAV, it returns to the USV base.

We design and develop an USV which can operate these steps in Fig.1.

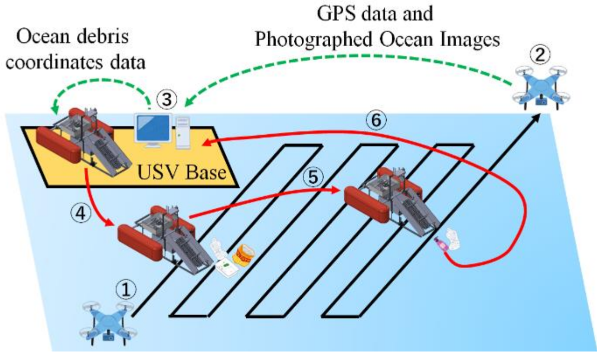

Fig. 1. The proposed ocean debris collecting operation method using UAV and USV

2,1. *Design condition and specifications of USV*

The USV is necessary several condition to operate the proposed ocean debris collecting method in Fig.1. The design conditions of ocean debris collecting USV are described below.

(i) Omnidirectional movement on the ocean surface
(ii) Equipment of ocean debris collecting device
(iii) Equipment of sensors and process unit for automounts debris collecting mission

The designed ocean debris collecting USV, which considered the design conditions, is shown in Fig.2, and top and side view of designed ocean debris collecting USV is shown in Fig.3.

As shown in Fig.2, the designed ocean debris collecting USV is consists of collecting device, debris box, cameras, wi-fi router, buoyancy and waterproof box.

As shown in Fig.3, the thrusters for omnidirectional movement are diagonally mounted to consider design condition (i), and the ocean debris collecting device is equipped on the front of USV for the design condition (ii). Also, the waterproof box is mounted to arrange electronic components such as sensors, battery and process unit to design condition (iii).

The power and communication system diagram, which include electronic components inside of the waterproof box, is shown in Fig. 4.

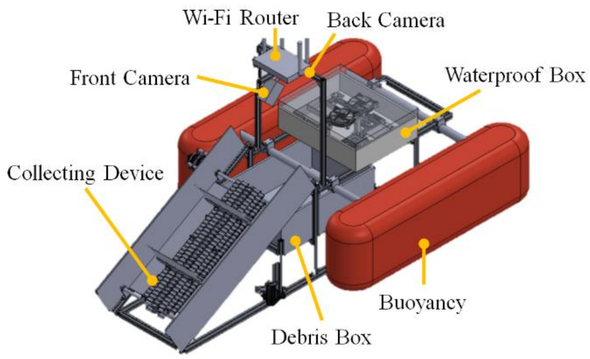

Fig. 2. Overview of designed ocean debris collecting USV

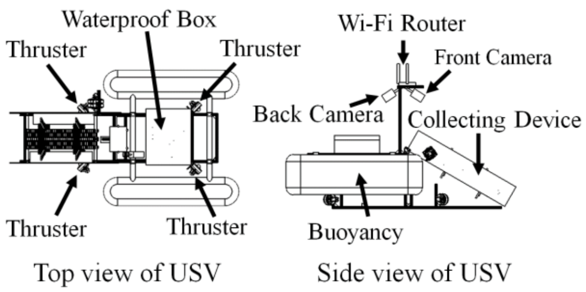

Fig. 3. Top and side view of designed ocean debris collecting USV

As shown in Fig.4, 14.8[V] Li-ion battery is employed as the main power source, and then DC 12[V] and DC 5[V] are transformed by the DC-to-DC converters. The network cameras, which contain power source and Wi-Fi communication board, are equipped as the front camera and back camera. The IMU and GPS sensor are communicated using USB serial communication to the computer. The computer, which contain I/O port, is send the PWM signal to motor drivers to operate the thrusters and ocean debris collecting device. The detail of designed ocean debris collecting USV is shown in Table 1.

As shown in Table 1, the size of designed USV is 1.9[m] x 1.2[m] x 1.3[m], and the weight is 35[kg].

2.2 *Development of ocean debris collecting device*

The ocean debris collecting device, which is equipped on the front of USV, was developed with the motif of a belt

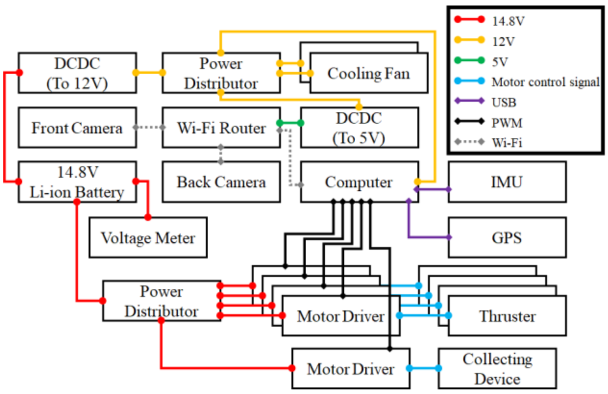

Fig. 4. Overview of power and communication system diagram for ocean debris collecting USV

Table 1. Detail of designed ocean debris collecting USV

Detail	Values
Size	1.9m×1.2m×1.3m
Weight	35kg
Sensors	IMU, GPS, Camera×2
Computer	LattePanda alpha 864s
Equipment	Thruster×4, Wi-Fi Router, Collecting Device
Battery	14.8 V Li-ion battery

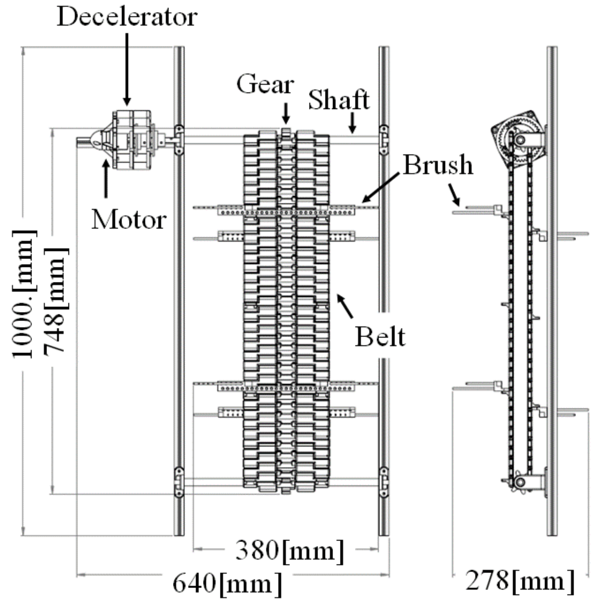

Fig. 5. Overview of designed ocean debris collecting device

conveyor. The designed collecting device is shown in Fig.5.

As shown in Fig.5, the designed collecting device is composed of brushes, belt and the decelerator with a motor. The brushes are carried ocean debris on the belt, and then the belt is moved to the debris box. The decelerator with a motor is necessary to rotate the belt which is need high torque. Before the motor selection and design of the decelerator, we calculated the necessary torque to operate the ocean debris collecting device. The force toward driving direction of ocean debris collecting device can be defined as follows:

$$F = F_b + \frac{m_b}{2} \cdot g \cdot \mu \cos\alpha + m_w(\sin\alpha + \mu\cos\alpha) \quad (1)$$

where F is force toward driving direction, F_b is external force on the brushes by the fluid resistance, m_b is mass of belt, g is gravitational acceleration, μ is coefficient of friction of belt, α is belt conveyor tilt angle and m_w is maximum collectable mass of ocean debris. In the designed collecting device, F_b was 8[N], m_b was 3[kg], α was 30[deg.], μ was 0.492, which is made by PLA [11], and m_w was 10[kg], therefore the F was about 105[N].

The load torque for rotation of ocean debris collecting device can be defined as follows:

$$\tau_L = \frac{F \cdot D \cdot s}{2 \cdot \eta_b \cdot i} \quad (2)$$

where τ_L is the load torque, D is diameter of gear, η_b is efficiency of belt mechanism and i is reduction ratio of designed decelerator.

In the designed collecting device, D was 0.03[m], s was factor of safety, η_b was 0.7 and i was 10. As a result, the τ_L was about 0.45[Nm].

Therefore, we selected a motor, which can output more than 0.45[Nm], and designed a decelerator to output the about 1:10 reduction ratio.

The detail of selected a motor shown in Table 2.

As shown in Table 2, we select a BLDC motor which output 0.5[Nm] as the maximum torque to rotate the designed ocean debris collecting device.

The designed decelerator to output about 1:10 reduction ratio is shown in Fig. 6.

As shown in Fig.6, the designed decelerator employed the planetary gear mechanism because it is compact and provide high power density in comparison to standard parallel axis gear trains [12].

The reduction ratio of designed decelerator can be defined as follows:

$$i = \left(\frac{z_a}{z_a + z_c} \cdot \eta_i\right)^2 \quad (3)$$

where z_a is number of teeth of the sun gear, z_c is number of internal gear teeth and η_i is efficiency of decelerator.

In the designed decelerator, z_a was 12, z_c was 42 and η_i was 0.7. Therefore, the i was about 10. The developed USV, which is mounted the developed ocean debris collecting device, is shown in Fig. 7.

As shown in Fig.7, the ocean debris collecting device is mounted on the front side of USV. User can access to USV inside the computer via the Wi-Fi router and whole the electronic parts in the system diagram, which is shown in Fig.4, could be confirmed the operation. The operation scene of collecting device, which is mounted USV, is shown in Fig. 8.

The brushes on the belt are rotated by decelerator, and the plastic bottles on the surface are carried to colleting box as shown in Fig. 8.

Table 2. Detail of selected a motor for collecting device

Detail	Values
Operating voltage	6V ~ 20V
Maximum ampere	22A
Maximum torque	0.5Nm
RPM/V	490 RPM/V

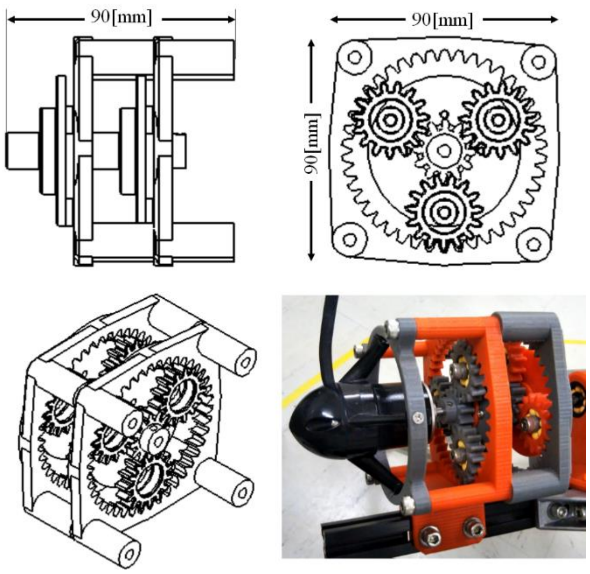

Fig. 6. Overview of the developed decelerator

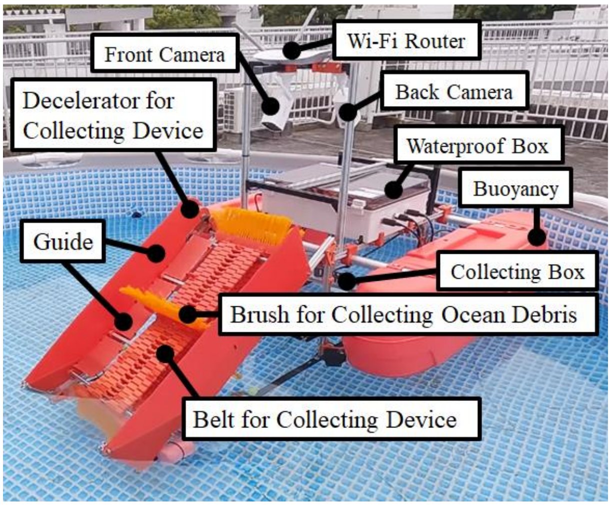

Fig. 7. Overview of the ocean debris collecting USV

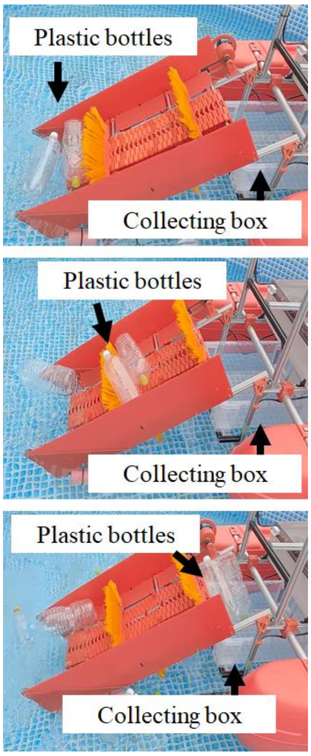

Fig. 8. Operation scene of ocean debris collecting device

3. Evaluation experiment of ocean debris collecting device with USV

We experiment the developed ocean debris collecting device with USV using the various size plastic bottles to check the collecting properties of device.
The detail of experiment is shown in Fig.9.
As shown in Fig. 9, the USV move toward a plastic bottle while operating the collecting device. For the evaluation, we set experimental condition about plastic bottle type, attitude and amount of water inside. For the condition of plastic bottle type, we employed 5 types of plastic bottles, which have different amount, such as 350, 500, 750, 1000, 1500 and 2000[ml]. For the condition of plastic bottle attitude, we set 3 angle of plastic bottles such as 0, 45 and 90 [deg.]. For the condition of amount of water inside,

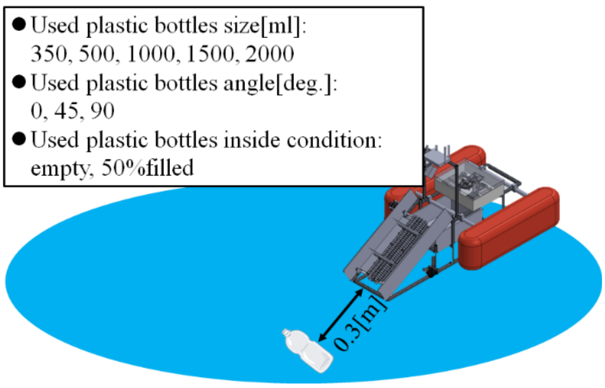

Fig. 9. Detail of debris collecting experiment

Table 3. Experimental result of whole condition

Bottle type	Inside condition	Angle [deg.]	Collecting rate [%]
350ml	Empty	0	50
		45	40
		90	50
	50% filled	0	60
		45	40
		90	10
500ml	Empty	0	80
		45	60
		90	30
	50% filled	0	50
		45	30
		90	30
750ml	Empty	0	80
		45	70
		90	50
	50% filled	0	40
		45	30
		90	10
1500ml	Empty	0	80
		45	70
		90	90
	50% filled	0	60
		45	50
		90	10
2000ml	Empty	0	80
		45	50
		90	30
	50% filled	0	30
		45	50
		90	20

we set 2 amount such as empty and 50% filled. The distance between USV and plastic bottle is 0.3[m] as shown in Fig.8. Each experimental condition was replicated 10 times. The experimental result is shown in the table 3.

As the result in Table 3, the average collecting rates for whole conditions was 47.7%. Also, collecting rates was 67% when the angle of plastic bottles was set 0[deg.] which is horizontal position with the USV.

4. Conclusion

In this paper, we designed and developed the ocean debris collecting USV and the developed ocean debris collecting device was evaluated using the plastic bottles of various type in the tank environment.

The reason for the focus on plastic bottles is that it accounted for the second largest number of ocean garbage worldwide [6]. Then, the plastic debris are caused the micro plastic problems [1], [2]. For this reason, we have selected plastic bottles as the important collect target and experimented.

In the USV development part, we designed the power and communication system to enable autonomous operation. In the ocean debris collecting device development part, we designed the belt conveyor type device and the decelerator of planetary gear mechanism to operate the designed ocean debris collecting device.

By the experiment, it has been confirmed that the developed USV could collect the target with a simple forward motion. As the results, the average collecting rates for whole conditions was 47.7% and the average collecting rates was 67% when the angle of plastic bottles was set 0[deg.] which is horizontal position with the USV. Also, the average collecting rates was 74% when the bottle was empty, and the angle was set 0[deg.]. Therefore, to improve the collecting rate, it is necessary to control the posture of USV and the debris. From these experimental results, it is expected that a strategy for autonomous collection of marine debris will be possible as the future work.

For the ocean environment operation, self-localization, navigation during the influence of waves, such as collection motion and obstacle avoidance, are required. Also, we will modify the USV to collect various type of debris as the future work.

In the future, we will solve these problems and try to make practical use of the USV for ocean debris collecting operations.

Acknowledgements

This research was supported by the 2021 University Research Grant of the Satake Technology Foundation.

References

1. D. K. A. Barnes, et al., “Accumulation and fragmentation of plastic debris in global environments”, Philosophical transactions of the royal society B: biological sciences, Vol. 364, No. 1526, pp.1985-1998, 2009.
2. L. Lebreton, et al., “Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic”, Scientific reports, Vol. 8, No. 1, pp.1-15, 2018.
3. L. Lebreton, et al., “A global mass budget for positively buoyant macroplastic debris in the ocean”, Scientific reports, Vol. 8, No. 1, pp.1-10, 2019.
4. S. C. Gall, et al., “The impact of debris on marine life”, Marine pollution bulletin, Vol. 92, No. 1-2, pp.170-179, 2015.
5. A. H. Tanis, “The Ocean Cleanup Barrier: A hydro-elastic model for fatigue lifetime assessment of The Ocean Cleanup barrier”, Master thesis of Delft University of Technology, pp.1-154, 2016.
6. Ocean Conservancy, “30th Anniversary International Coastal Cleanup”, pp.1-28, 2016.
7. M. Lawn et al., “Proposed use of a Semi-Autonomous All-Terrain Amphibious Vehicle to improve coastal cleanup efficiency”, IEEE OCEANS 2021: San Diego, pp.1-4, 2021.
8. J. E. Manley, “Unmanned surface vehicles, 15 years of development”, IEEE OCEANS 2008: Quebec, pp.1-4, 2008.
9. Y. Chen et al., “Path Planning and Obstacle Avoiding of the USV Based on Improved ACO-APF Hybrid Algorithm With Adaptive Early-Warning”, IEEE Access, vol. 9, pp. 40728-40742, 2021.
10. X. Zhou et al., “Learn to Navigate: Cooperative Path Planning for Unmanned Surface Vehicles Using Deep Reinforcement Learning”, IEEE Access, vol. 7, pp. 165262-165278, 2019.
11. W. Pawlak, “Wear and coefficient of friction of PLA-graphite composite in 3D printing technolo，International Conference Engineering Mechanics 2018, pp.649-652, 2018.
12. P. Lynwander, “Gear Drive Systems: Design and Application”, Marcel Dekker, New York, 1983.

Authors Introduction

Prof. Jonghyun Ahn

He is an Assistant Professor of Dept. of Intelligent Mechanical Engineering, in Hiroshima Institute of Technology, Japan. He graduated from the degree in underwater robotics Kyushu Institute of Technology, in 2017. His research interests include marine robotics system, intelligent sensing, and underwater communication system.

Mr. Shunsuke Oda

He received his Bachelar's degree from the Dept. of Intelligent Mechanical Engineering, Hiroshima Institute of Tech-nology, Japan in 2022. He is currently a Master's course student in Kyushu Institute of Techno-logy, Japan.

Prof. Shota Chikushi

He is received his Ph.D. from the Kyushu Institute of Technology in 2018. From 2018 to 2022, he was a project assistant professor and an assistant professor at The University of Tokyo. Since 2022, he is a lecturer at Kindai University. His research interests are field robotics and unmanned construction system. He is a member of IEEE, RSJ and JSPE.

Prof. Takashi Sonoda

He is an Associate Professor of Dept. of Engineering, Nishinippon Institute of Technology, Japan. His research interests include the underwater robotics system and robot manipulator system.

Prof. ShinsukeYasukawa

He received the Ph.D. degree in electrical, electronic, and information engineering from Osaka University, Japan, in January 2017. Currently, he is an Associate Professor of Dept. of Human Intelligence Systems, Kyushu In-stitute of Technology, Japan. His research interests include information processing in biological sensory systems and their applications in robotics.