Journal of
Marine Science and Technology

Volume 28 | Issue 5 Article 3

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Recommended Citation
Yamamoto, Ikuo; Morinaga, Akihiro; and Lawn, Murray (2020) "AGILE ROV FOR UNDERWATER SURVEILLANCE," *Journal of Marine Science and Technology*: Vol. 28: Iss. 5, Article 3.
DOI: 10.6119/JMST.202010_28(5).0003
Available at: https://jmstt.ntou.edu.tw/journal/vol28/iss5/3

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Acknowledgements

The authors would like to express their sincere gratitude to members of the Yamamoto Lab. for their cooperation in regard to this work, with particular appreciation to Ryosuke Funaki, Kodai Sadano, Tsubasa Nakano, Shogo Rikikusa, Yuto Kai, Yuu Kumamoto and Chikara Masuzaki

Journal of Marine Science and Technology, Vol. 28, No. 5, pp. 343-348 (2020)
DOI: 10.6119/JMST.202010_28(5).0003

AGILE ROV FOR UNDERWATER SURVEILLANCE

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Key words: ROV, underwater, surveillance, AI (artificial intelligence).

ABSTRACT

Surveillance of submerged plant is becoming increasingly critical as ocean based resources become more and more important. A wide varieties of new roles have recently emerged ranging from aquaculture to offshore power generation systems, in addition to the monitoring of the aging submerged sections of bridges, piers and dams etc. Consecutive generations of ROVs have been developed at Nagasaki University to meet the changing needs for surveillance of submerged plant. This paper outlines briefly the ROVs developed to date and the move to increase ROV autonomy using AI (artificial intelligence).

I. INTRODUCTION

Traditionally surveillance of submerged plant has been carried out by professional divers, clearly this involves significant cost and a varying level of risk depending on each location or situation. As robotic technology has advanced and of recent the use of AI, it has become possible to use an ROV (remotely controlled underwater vehicle) to carry out such tasks. Commercial ROVs however tend to be very expensive, large and require significant expertise in operating them. (Kumagai et al., 2000; Roman et al., 2000; Balasuriya and Ura, 2001; Sherman et al., 2001; Wasserman et al., 2003; Aoki et al., 2008; Fletcher et al., 2008; Marani et al., 2009; Shibata et al., 2010; Meinecke et al., 2011).

The more traditional need for such monitoring begins with checking the structural integrity of the submerged sections of transportation, port and hydro-electric infrastructure, bridges, piers, dams etc. Of more recent the increasing dependence on aquaculture and offshore energy also requires periodic inspection of submerged plant.

In the event of a disaster and/or an emergency situation the need for a rapid and safe means to evaluate submerged plant is critical.

In response to the above need, for a low cost, portable reliable, rapid and safe means to survey submerged plant the Yamamoto Lab. has continued to improve the ROVs to meet each of these needs using the state of the art technology.

II. A PRACTICAL ROV

A practical ROV is defined by the authors as follows;

- Easy to transport – ideally light enough to be carried by one person and small enough to fit in a regular car.
- The startup time should be short, a few minutes.
- The control should be simple enough for anyone with a little practice to be able to use.
- Several hours of operating time should be possible.
- High resolution images should be available in real time on a base station monitor.
- Sufficient lighting must be provided for dark and murky conditions.
- The cost of the entire system must be kept to a minimum.
- Depths of up to 100 meters must be considered.

Fig. 1 shows the first ROV developed at the Yamamoto Lab. which fulfilled the above requirements.

III. HARDWARE

1. 3D CAD

The above mentioned first generation ROV was designed in 3D CAD, and is shown in Fig. 2. The main specifications were as follows;

- Length 619 mm, width 419 mm, height 233 mm and weight 5.6 kg.
- The main body material was Polyvinyl chloride pipe.
- Cable length 100 m.
- Five Mayfair Marine thrusters were used (2-4A, 48v).
- GoPro HD Hero2 1920 x1080 px, 30 fps, 170 degree view angle.
- Four led arrays.
- Operating speed 0.5 - 1.0 m/sec.

Details of this mechanism are provided in (Yamamoto et al., 2013), in particular the balance system used, whereby the upper section contributes buoyancy, and the lower section ballast. Static balance is therefore inherent, while adjustable weights provided for fine adjustment.

Paper submitted 01/29/20; accepted 03/05/20. Corresponding Author: Ikuo Yamamoto (e-mail: iyamamoto@nagasaki-u.ac.jp)

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Fig. 1. ROV

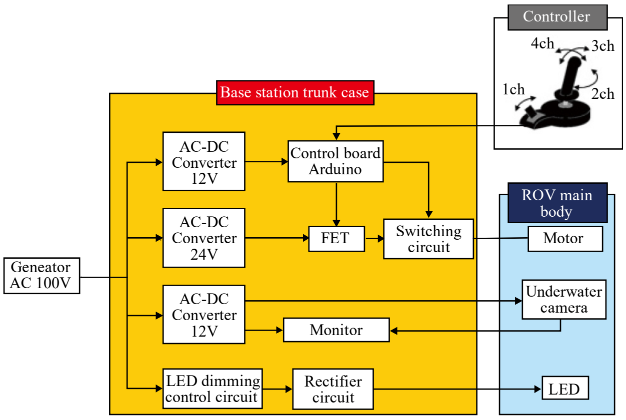

Fig. 3. ROV system schematic

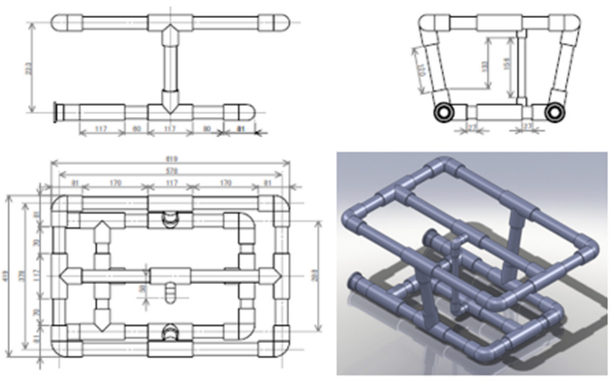

Fig. 2. Frame design

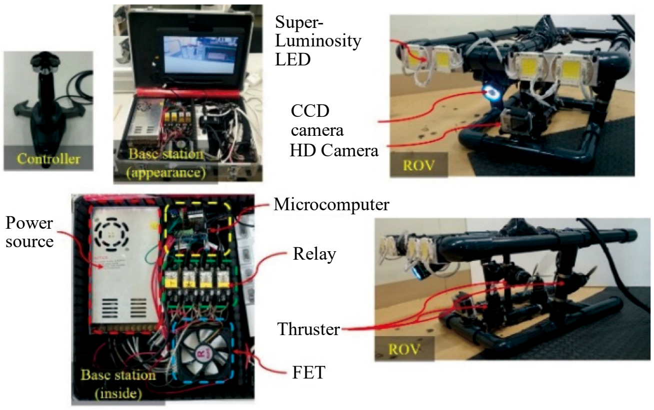

Fig. 4. The monitoring system

2. System Functionality

The above ROV system schematic is shown in Fig. 3, an Arduino microcontroller was used. System power was provided by a 900w gas engine generator (~ one gas cartridge per hour of operation). The control system is proportional control providing for omnidirectional maneuvering, forward, reverse, port, starboard, yaw, surfacing and diving. As can be seen in Fig. 4 the controller including monitor is housed in a convenient carry case. A minimum of two operators are required.

3. Umbilical Cable

The umbilical cable shown in Fig. 5 consisted of power and control lines, floats spaced at about 1 m compensate for the cable weight to provide neutral buoyancy.

4. Portable Control-Station

The control-unit shown in Fig. 6. provides for ROV control via a joystick shown in Figs. 3 and 4, monitor, and image recording.

5. System Control

As mentioned above, five thrusters provide the necessary propulsion for the ROV, the proportional control uses PWM (Pulse Width Modulation) actuation. An Arduino microprocessor reflects movement of the joystick to provide proportional control to all five thrusters simultaneously. This interface is quite intuitive and with a little practice the average inexperienced operator can maneuver the ROV as required.

IV. EXPERIMENTAL RESULTS

Fig. 7 shows the ROV in Chatan, Okinawa, Japan, despite 1.0-1.5 tidal currents and 10m/sec. winds the ROV was able to acquire the necessary target images and went on to win the best ROV Underwater Robot Contest in 2014 in Okinawa (Yamamoto et al., 2016).

This ROV was later used to inspect the base of an offshore wind generator spar in Goto, Nagasaki, Japan (Depth: 76m) Fig. 8.

V. PERFORMANCE EVALUATION

This and later ROVs developed at the Yamamoto Lab. have focused on meeting local needs, which included consideration for portability (easy to transport), user-friendliness, and practicality. Quantitive assessments have yet to be carried out on

Fig. 5. Umbilical cable and floats

Fig. 6. Portable base-station

these ROVs however some general comments are made regarding each of these attributes.

1. Maneuverability

Further to the above-mentioned performance in Okinawa, after extensive offshore sea trials in Shibushi, Koagoshima, Japan, the ROV structure was altered to improve the maneuverability in faster tidal flows and rough conditions (Yamamoto et al., 2013).

2. Control

Further to the above-mentioned comments on control, aspects that remain a little difficult to grasp are initial orientation and using the thrusters to counter tidal flows, perhaps accelerometers could be used to compensate for these flows to assist in maintaining a fixed location.

3. Portability

Also mentioned above, the aspect of portability is essential

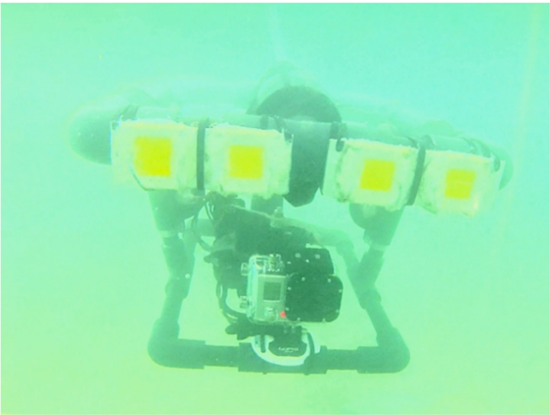

Fig. 7. ROV experiment in the sea

Fig. 8. Real time monitoring at the base of an offshore wind generator spar

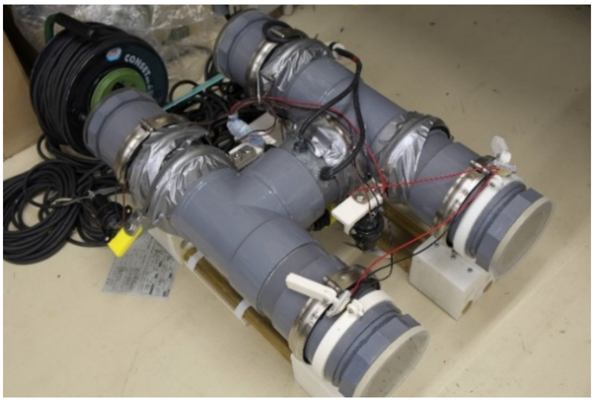

Fig. 9. Kenbot ROV

in providing a practical solution, typically a regular car and some manhandling or car, manhandling and boat are necessary to access the target location.

4. Practicality

Experiments to date have indicated these ROVs are practical for the intended purposes, there is however the need to

Fig. 10.Top: Target dam, lower left: Penstock intake, lower right: image at a depth of about 100m – to confirm camera resolution

Fig. 11. Seabot ROV

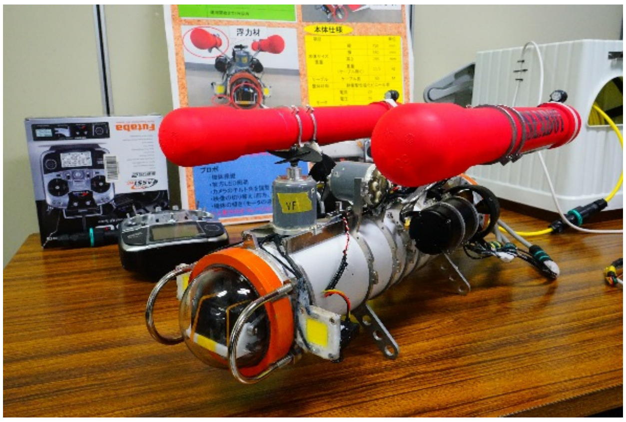

Fig. 12 Smart Caibot III ROV

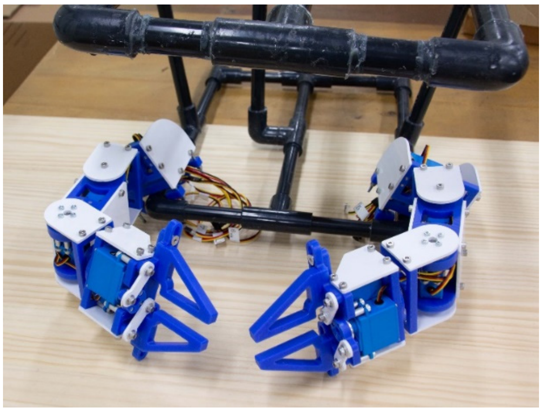

Fig. 13. ROV hand like manipulators

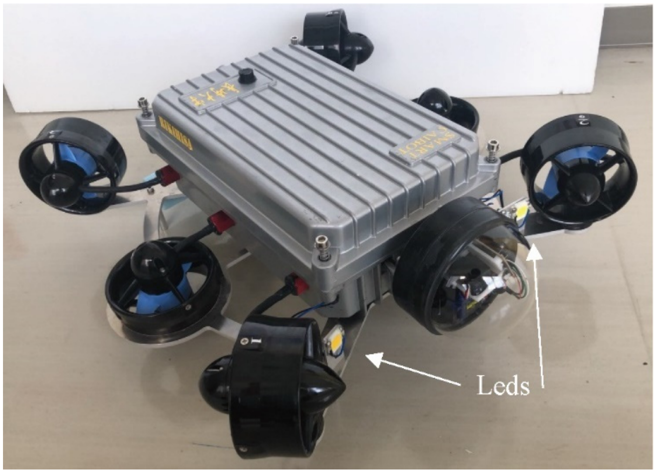

Fig. 14. Smart Caibot ROV

increase the robustness, as they often need to be thrown into the sea (to clear the side of the wharf or boat), and likewise when being recovered will often crash into the wharf or boat to some degree depending on the conditions. Also there is the need to increase the capability of the ROVs for the monitoring of tidal generators under peak tidal flow (3+m/s).

The ROV shown in Fig. 9 was used to inspect the Nagatani dam, Fukuoka, Japan shown in Fig. 10, here a sample image was placed at a set depth to confirm the resolution of the camera at a depth of about 100m, the target dam and sample images are shown in Fig. 10. This ROV received an award from the Japanese government in 2015. Two of the Seabot series ROVs are shown in Figs.11 and 12 they provide underwater image recognition. The Seabot ROVs won best ROV awards in 2016 and 2018 as part of the Underwater Robot contest held yearly in Okinawa, Japan.

5. Mechanisms under progress

A number of additional mechanisms are under development, firstly with reference to Fig. 13. Robotic manipulators are being fitted to an ROV to provide some ability to carry out simple tasks, such as clearing biofouling or debris that may restrict visual access to a given area. In the case of significant force and or dexterity being required a diver will be required. The robotic arms shown consist of waterproof servo motors providing five degrees of freedom, two elbow joints, wrist rotation

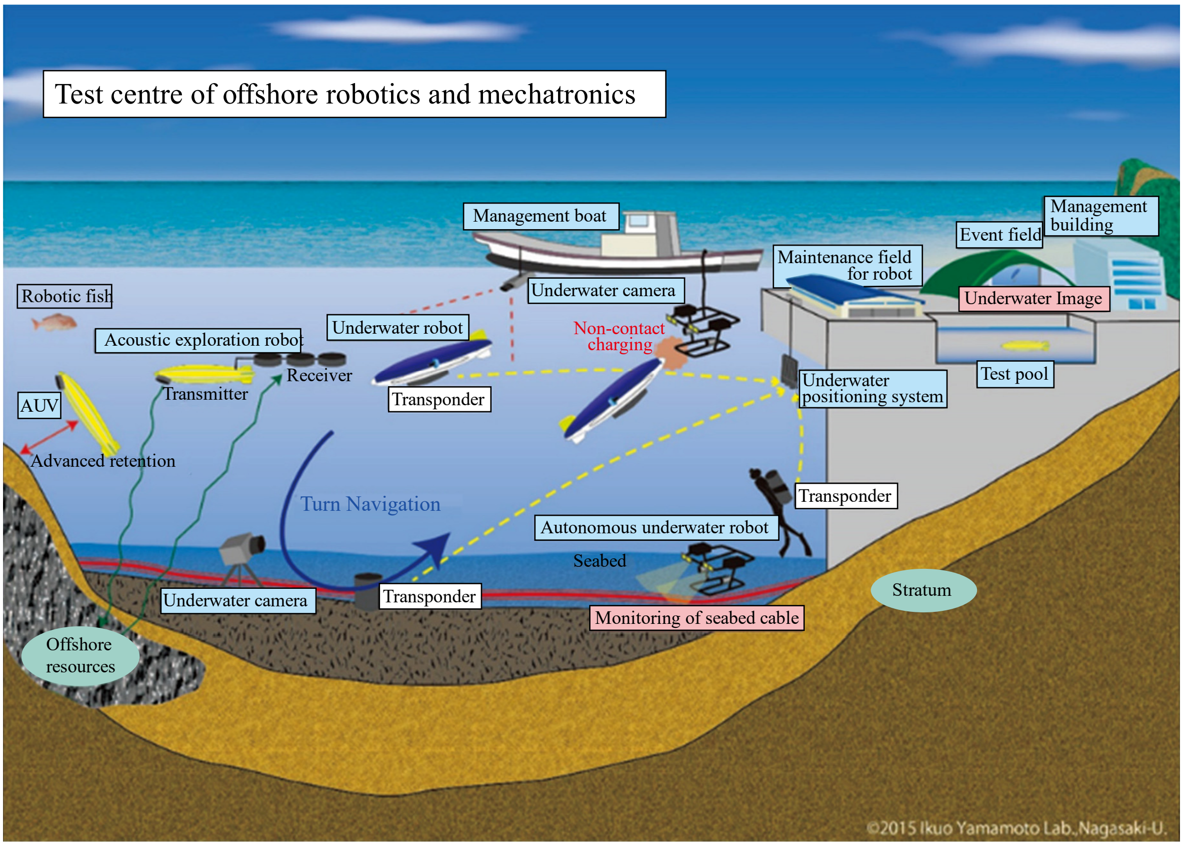

Fig. 15. Offshore test concept for underwater robotics and mechatronics

and a parallelly actuated mandibles.

The authors are also working to develop of an AUV/ROV underwater docking system supported by the Nippon foundation and Mitsubishi Heavy Industries, Ltd and SDI (Scottish Development International) Scotland UK. The overall application is based on the automation of such underwater monitoring and is illustrated in Fig.15.

VI. AGILE ROV - AI

The most recent addition to the Yamamoto Lab. ROVs is referred to as the Smart Caibot ROV, shown in Fig. 14. Major changes to the design include the use of a solid aluminum case over plastic pipes and the diagonal configuration of the horizontal thrusters (vectored horizontal thrust). The main specifications are a width of 420 mm, length of 490 mm, and a height of 160mm. The ROV weight is 6.9 kg (including 2 x 11.1v 8Ah batteries). This thruster configuration provides improved performance in stronger sea currents as well as providing greater maneuverability (Li et al., 2019). While clearly a custom designed body would reduce the horizontal hydrodynamic drag, two of the targets of these ROVs are low cost and usability, using an off-the-shelf case reduces the cost significantly and the removal of 4 screws provides full access to the control circuits and batteries. Previous models have been problematic in regard to accessing and resealing the various cavities for deep diving, on this model most of the control system and batteries can be accessed and resealed within minutes using a power driver set to the appropriate torque (for sealing).

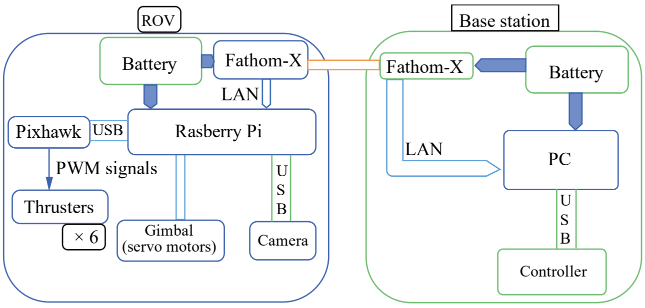

Fig. 16. Caibot system configuration

The system configuration of the Caibot is shown is Fig. 16, a Rasberry Pi is the main processor, relaying control data via a Fathom-X (ROV tethering system) to a Pixhawk (programmable flight controller), as well as in this case has been provided with AI to lock the ROV onto a user defined object using image template matching, here the control of the ROV compensates for tidal flow and other disturbances and combined with use of a Gimbal mechanism within the camera case assists to lock on to the target image. The ability to lock onto an object is limited to the operating limits of the ROV which are a maximum operating speed of approximately 1.5m/s, a maximum diving depth 40m and operating time about 3 hours on a single charge.

VII. CONCLUSIONS

This paper has presented the Yamamoto Lab. ROVs developed to date. As the need to monitor underwater equipment increases so does the need to be able to check it as safely, quickly, easily, and inexpensively as possible. The ROVs presented each provided a range of features to suit specific tasks, these tasks included maximum depths to 100m, operating times up to 3h, operating speeds of up to 1.5m/s and in the case of the most recent Smart Caibot ROV using AI, the ability to lock the ROV onto a given object providing disturbances do not exceed the operating limits of the ROV itself.

Aspects under development include the need for increased robustness given the harsh operating conditions particularly in the open sea, the need for greater operating speed to enable the observation of tidal power generators and the need for the addition of manipulators to provide some degree of dexterity. However, as the provision of increased functionality tends to be mutually exclusive, for example providing increased speed and dexterity, the need to tailor ROVs to meet specific for specific purposes will be inevitable

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to members of the Yamamoto Lab. for their cooperation in regard to this work, with particular appreciation to Ryosuke Funaki, Kodai Sadano, Tsubasa Nakano, Shogo Rikikusa, Yuto Kai, Yuu Kumamoto and Chikara Masuzaki

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