ASV MAINAMI for AUV monitoring and its sea trial

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***Abstract*—JAMSTEC has proposed an operation of multiple AUVs using an ASV (Autonomous Surface Vehicle) to improve survey efficiency. For this purpose, an ASV "MAINAMI" with a length of 6 meters has been developed since 2013. The vehicle is equipped with an acoustic communication device and a satellite one, in order to relay information between an AUV and operators on a ship or on land. In February 2016, its sea trials were carried out at Suruga-Bay. The performance of its solo navigation was verified through the sea trial. And, the ASV succeeded in tracking of a deep-tow as a simulated curing-type AUV.**

Keywords—ASV; AUV; multi-vehicle operation; sea-trial

I. INTRODUCTION

Seabed mineral resources in Japan's exclusive economic zone (EEZ) is expected as one of new economic potential sources. Recently, the investigations have been conducted using AUV [1-3]. And, many hydrothermal deposits have been discovered in Izu-Ogasawara Arc and Okinawa Trough [2][3].

AUV is a powerful platform for investigations of seabed resources. AUV can cruise a predefined route autonomously to achieve a high-resolution geometry and a successive seawater profile. However, a support vessel conventionally monitors only one AUV during its whole dive for safety and positioning. Therefore, the survey efficiency is limited.

ASV (Autonomous Surface Vehicle) is one of solutions to improve the survey efficiency [4][5]. We have proposed an operation system of multiple AUVs using an ASV. Fig.1 shows our concept. Instead of a vessel, an ASV tracks an AUV and relay information between the AUV and operators on a vessel. For this purpose, we have been developing a multi-vehicle operation system using an ASV with a budget of Japanese Cross-ministerial Strategic Innovation Promotion Program (SIP) [6]. In this paper, we explain the newly developed ASV "MAINAMI" and its sea trials.

II. ASV "MAINAMI"

ASV "MAINAMI" has been developed in JAMSTEC since 2013. The length is 6 meters and the weight is 3 tons. The general arrangement, specification of the vehicle are shown in Fig.2 and Table I, respectively. The vehicle has a keel along the bottom that keeps it steady.

The main purpose is monitoring of an AUV during its dive. The ASV has three main functions; AUV localization, tracking, and communication.

- AUV localization

The vehicle has an acoustic device for communication with an AUV and a SSBL system for position measurement of the AUV. We arrange the devices in the keel to keep away from noise sources, i.e. the diesel engine and the thrusters. A motion compensator stabilizes attitude angles and heave motion of the acoustic devices [7].

For tracking, ASV should estimate AUV's state in real-time. ASV obtains information of AUV's state through SSBL system and uplink communication. AUV position is measured by SSBL positioning system. Navigation data of AUV, e.g. attitude, speed and depth, are measured by on-board sensors such as INS, DVL and depth sensor. And ASV receives the AUV navigation data through acoustic uplink communication.

We have proposed a localization method based on a stochastic approach called the Particle Filter [5]. The measurements are fused by particle filter, in order to realize stable estimation robust against sensor noises and lack of measurements.

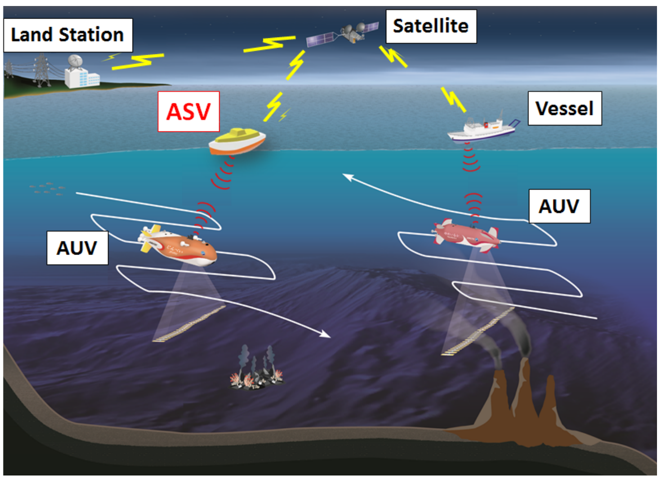

Fig. 1. A multi-vehicle operation system using an ASV and a satellite communication.

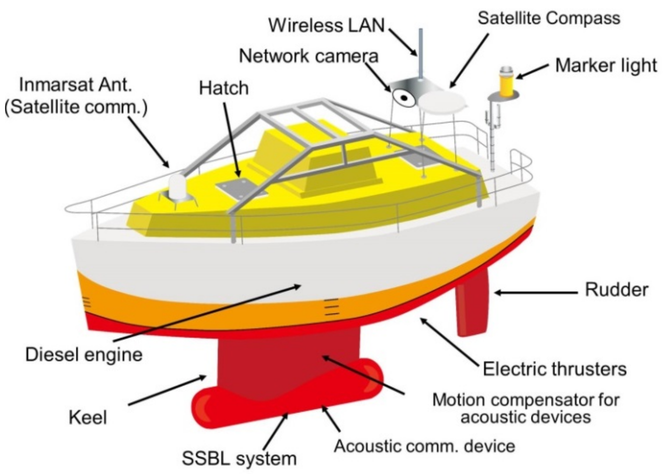

Fig. 2. General arrengement of the ASV “MAINAMI”.

Fig. 3. Recovery scene of ASV “MAINAMI” at sea trial in Suruga-Bay.

TABLE I. SPECIFICATION OF ASV “MAINAMI”

Size	6.0m(L)×2.6m(W)×3.2m(H)
Weight	3 ton
Max. Speed	5 knots
Duration	48 hours @ 2knots
Actuators	Thrusters (3kW) × 2 Rudder× 1
Power	Diesel engine (11.5kW) Lead battery
Navigation devices	GPS satellite compass, AIS
Observation devices	Anemometer, Network camera
Communication	Acoustic comm., Satellite comm., Wireless LAN
Operation mode	Autonomous, Remote control
Control unit	Distributed CPU system
OS	Linux

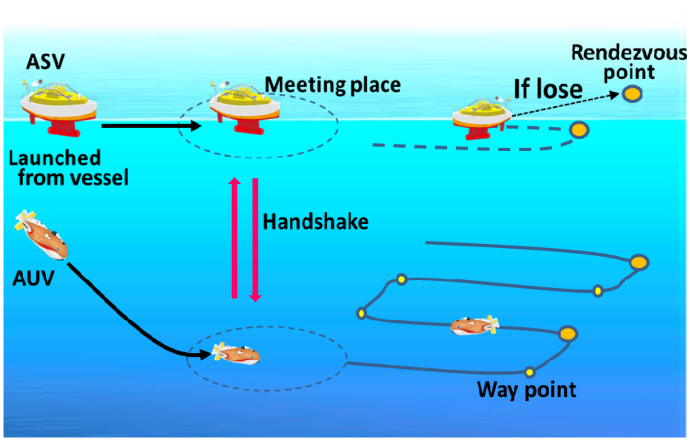

Fig. 4. A stratey of an AUV tracking

- Tracking

In the design, we assume that an AUV cruises at a speed of 2knots. And, its operation depth is from a few hundred to 3,000 meters. We plan to operate 3,000 m class AUV “Yumeiruka” or “Jinbei” [1]. The ASV has a diesel engine, two electric thrusters and a rudder. The maximum speed is 5 knots so that the vehicle can track an AUV against a current and a wind.

- Communication

For communication with an operator on support vessel or on land, the vehicle is equipped with wireless LAN, VHF, Iridium and Inmarsat. We use the different means according to the communication distance; wireless LAN up to 1-2 km, VHF up to 10km, and satellite any more. In operation, the communication helps safety operation of the vehicles. We can monitor their status and video image of a network camera mounted on the ASV in real-time. And, we can send a command to the AUV as well as the ASV.

III. AUV TRACKING METHOD

Our concept is tracking control rather than cooperative control. AUV cruises its route independently and ASV tracks the AUV, except at start and in case of emergency.

A. Tracking Strategy

The tracking strategy consists of several steps as shown in Fig.4. Firstly, ASV and AUV are launched from a vessel at survey area. Secondly, the vehicles reach to a meeting place and wait respectively. Then ASV confirms the state of SSBL positioning, acoustic communication, and AUV’s navigation. And ASV sends commands of position update and the start of a cruise. Next, AUV cruises a pre-defined route and ASV tracks the AUV based on its estimated position.

In the pre-defined route, there are some rendezvous points. When ASV loses AUV’s position for a certain period, ASV goes to a next rendezvous point and waits for AUV. On the other, AUV continues the cruise as scheduled before the vehicle reaches to the rendezvous point. At the rendezvous points, ASV and AUV confirm the existence each other. The vehicles don’t restart unless without the confirmation.

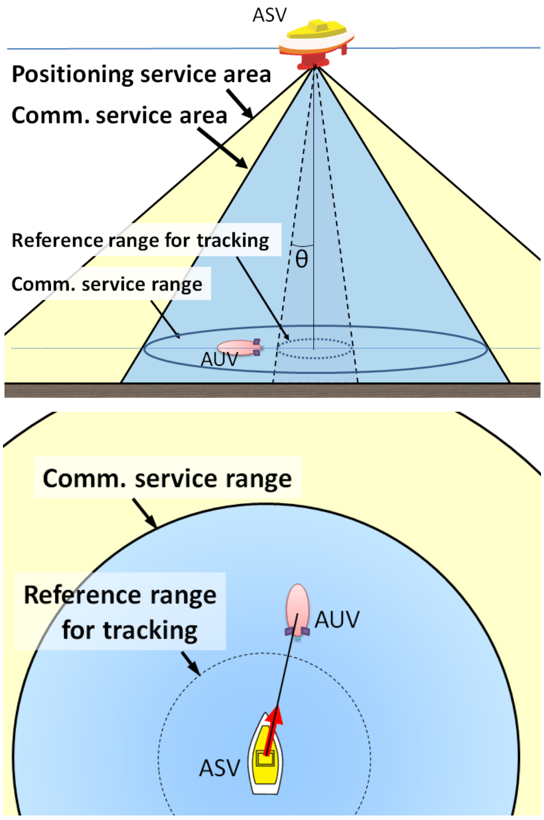

Fig. 5. Coverage areas of acoustic communication and SSBL positioning. (Upper figure: side view. Lower figure: top view)

B. Tracking Control Algorithm

Tracking algorithm is simple. Speed control of ASV is based on a position relation of ASV and AUV. Fig. 5 shows coverage areas of acoustic communication and SSBL positioning. The coverage area is proportionate to the depth of AUV. Normally, an acoustic communication device has narrower directionality to ensure S/N ratio. Lower figure of Fig.5 shows horizontal coverage range at a depth of AUV. Coverage range of communication is shorter than that of positioning. Therefore, the tracking control should navigate the ASV to keep the AUV in the communication service range steadily.

The basic concept is that ASV tracks from the backward of AUV. If ASV cruises right above AUV, it has a greater risk of collision when an emergency surfacing of AUV happens. And, ASV has higher-speed performance so that ASV catch up easier. Therefore, ASV tracks AUV keeping a certain distance.

Target orientation of ASV is the direction to AUV. Target speed of ASV is varied depending on the horizontal distance between ASV and AUV. Fig. 6 shows the position relation of the vehicles and ranges for speed control. Here, **D** is the horizontal distance between ASV and AUV. $\mathbf{r_1}$ is a speed-down range. $\mathbf{r_2}$ is a speed-down range.

- Speed-up mode when $\mathbf{r_2} < \mathbf{D}$

When AUV is outside of speed-up range, the target speed of ASV increases. Fig. 6 shows this case.

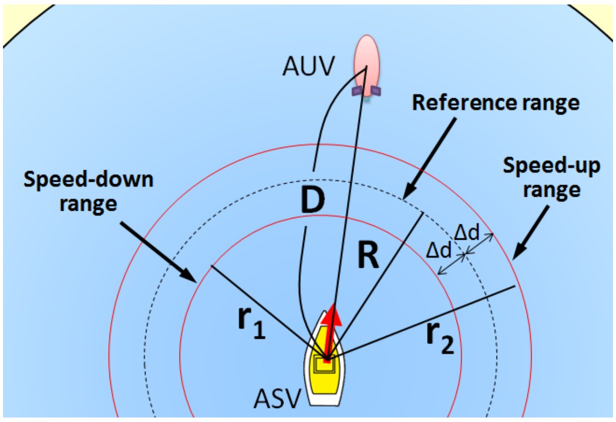

Fig. 6. Switching of speed control mode based on the horizontal distance between ASV and AUV.

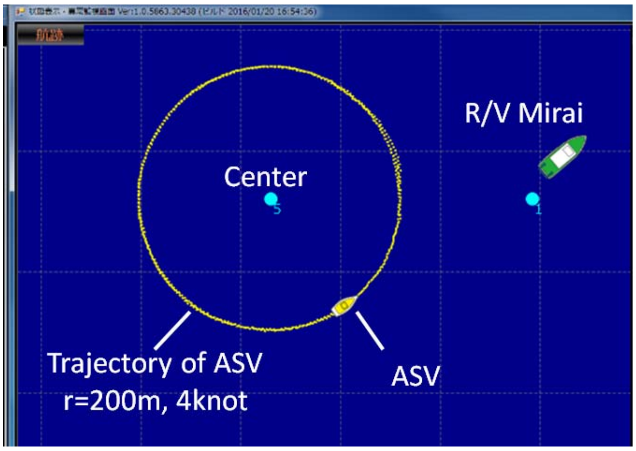

Fig. 7. Trajectory of the ASV "MAINAMI" during an experiment of navigation performance

- Constant-speed mode when $\mathbf{r_1} < \mathbf{D} < \mathbf{r_2}$

When AUV is between the ranges, the target speed maintains.

- Speed-down mode when $\mathbf{D} < \mathbf{r_1}$

When AUV is inside of speed-down range, the target speed decreases. However, there is minimum limit of target speed. The limit is minimum controllable speed with a rudder.

IV. Sea Trial

During MR16-01 cruise in February 2016, we launched the ASV "MAINAMI" at Suruga Bay. The ASV was deployed and recovered by a portside multiple-joint crane of R/V MIRAI. Fig. 3 is a photo taken at the recovery scene.

A. Experiment of solo navigation performance (Only ASV)

Fig. 7 is an image capture of a control GUI on R/V. In the experiment, ASV moved in the shape of a circle autonomously, at a speed of 4knot with a radius of 200 meters. The trajectory was measured by its GPS satellite compass. The ASV's control system based on PID algorithm controls its rudder and thrusters in real-time. The positioning error was within 5 meter.

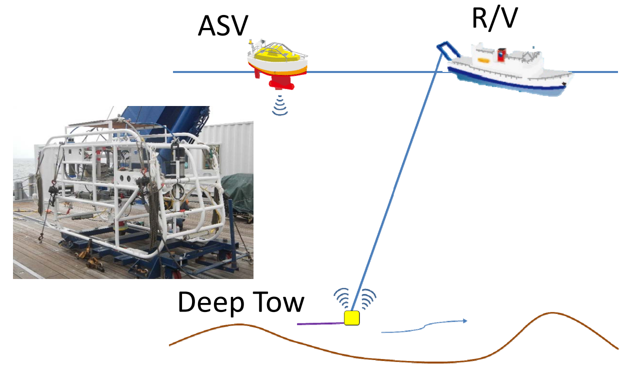

Fig. 8. Expermental configuration of target tracking.
The ASV tracked the deep-tow as a simulated cruising-type AUV.

TABLE II. EXPERIMENTAL PARMETERS OF TRACKING ALGORITHM

Target speed		
Initial		2.0 knot
Minimum		1.6 knot
Maximum		3.0 knot
Acceleration (step size)		0.05 knot/sec
Algorithm		
Time step		1 sec
Angle of reference range	θ	17.5 deg
Permissible width	Δd	±50 m

θ and Δd corresponds to symbols in Fig.5 and Fig.6 respectively.

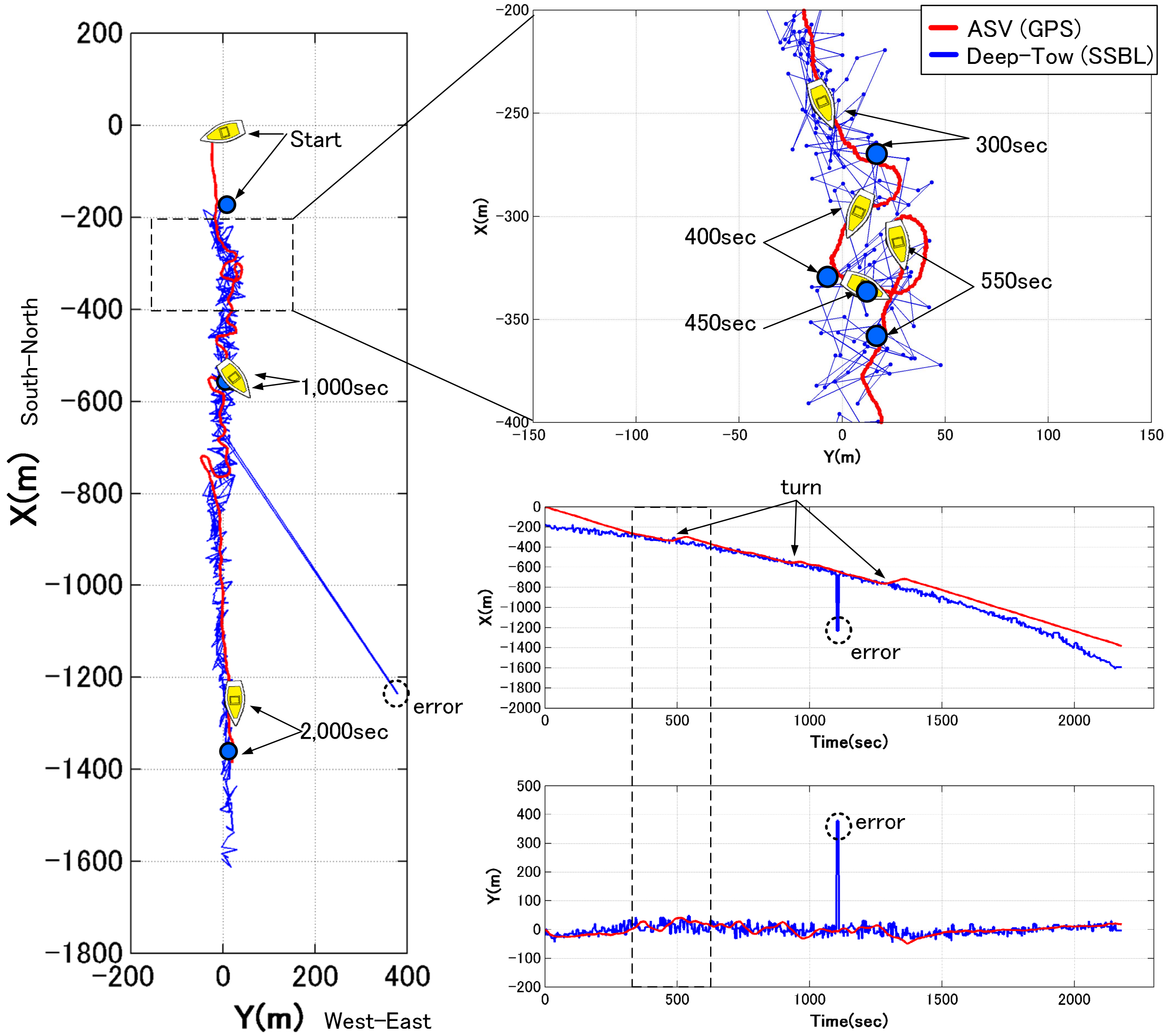

Fig. 9. Trajectory of ASV “MAINAMI” and a deep-Tow during an experiment of navigation performance.

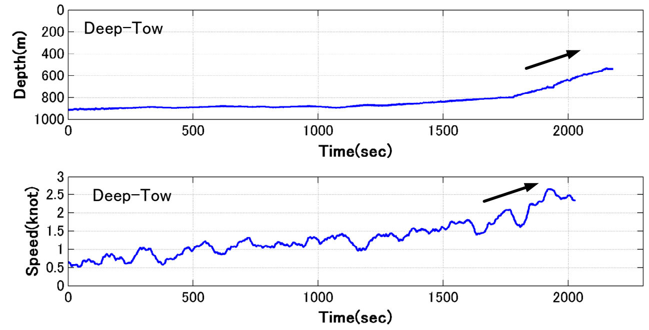

Fig. 10. The depth and speed of deep-tow during the experiment. The results correspond the trajcetory in blue line in Fig.9.

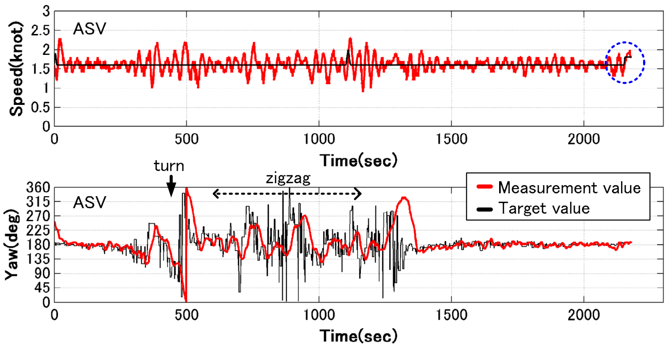

Fig. 11. The speed and yaw of ASV during the expriment. The results correspond the trajcetory in red line in Fig.9.

B. *Expriment of target tracking*

Fig. 8 shows the experimental configuration. This was the first trial of target tracking. Therefore, we used a deep-tow as a target for easier handling. In the experiment, ASV tracked the deep-tow as a simulated cursing–type AUV. The deep-tow was towed at speed of 0.5-2.5knot at a depth of 900-550m as shown in Fig.10. We used Evologics S2C R12/24 for acoustic communication and SSBL system. The acoustic devices were mounted on the ASV and the deep-tow. The directionality angle of the device is ±35deg.

The experimental parameters of tracking algorithm is shown in Table II. The range of target speed is 1.6-3.0 knots. The acceleration i.e. change rate of target speed is 0.05knot/sec during speed-up mode and speed-down mode.

In our system design, the angle of reference range θ is 5-10deg in normal setting. However, it was needed to keep ASV away from R/V for safety in the experimental configuration. The value 17.5deg indicates the half of the acoustic device's directionality. The reference range R is calculated as follow:

$$\mathbf{R} = \boldsymbol{depth}_{\mathbf{deep\ tow}} * \tan\theta. \quad (1)$$

Fig.9 shows trajectory of the ASV and the deep-tow. The red line shows the ASV's position measured by its GPS system. The blue line shows the deep-tow's position measured by SSBL system. The deep-tow was towed in southern direction. The depth and speed of the deep-tow during the experiment are shown in Fig.10. The speed and yaw of the ASV are shown in Fig.11. In fig. 12, the black line shows time series variation of

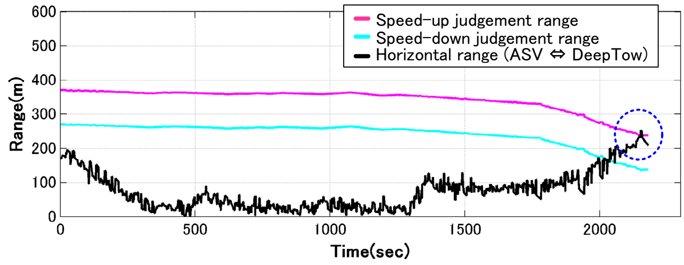

Fig. 12. Horizontal distance between ASV and deep-tow vs. speed-up and speed-down range.

the horizontal distance between ASV and deep-tow. The purple and blue lines show speed-up and speed-down range respectively.

At the beginning, the deep-tow was towed at a depth of 900m and at a speed of 0.5knot. And, it was located at 180m south of ASV. The target speed of ASV decreased 2.0 to 1.6 knots because deep-tow was located inside of speed-down range. However, the speed of ASV was still higher than that of deep-tow, so that ASV caught and passed deep-tow at 450sec. Then, ASV turned round because the target orientation was reversed. The upper right figure of Fig.9 shows the detailed trajectory at the period.

During 600-1,200 sec, ASV kept above deep-tow moving on a zigzag trajectory. After 1,400 sec, we started to shallow the deep-tow. Therefore, the speed-up range decreased shown in Fig.12. Furthermore, we started to increase the speed of the deep-tow at same time so that deep-tow went ahead of ASV. Finally, deep-tow went outside of speed-up range during 2,152-2,156 sec, and the target speed of ASV increased 1.6 to 1.8knots shown in Fig.11. Although the experimental course was single straight line, we verified the basic performance of tracking control.

V. Conclusion

In this paper, we proposed an operation of multiple AUVs using an ASV to improve survey efficiency. And, we explained a newly developed ASV "MAINAMI" and a AUV tracking method and algorithm. The performance of the method was verified through sea-trials. And, the ASV succeeded in tracking of a deep-tow as a simulated curing-type AUV. Based on the result, we plan to carry out sea trials that the ASV tracks a real AUV in near future.

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References

[1] T. Nakatani, H. Yoshida, T. Hyakudome, S. Ishibashi, M. Sugesawa, Y. Ota, H. Ochi, Y. Watanabe, T. Sawa, Y. Nakano, and H. Machiyama, "Dives of Cruising-AUV JINBEI to Methane Hydrate area in Joetsu knoll," OCEANS'13 MTS/IEEE, pp.1-5, San Diego, USA, Sept. 2013.

[2] H. Minami and Y. Ohara. "Detailed morphology and bubble plumes of Daiichi-Amami Knoll in the central Ryukyu Arc," Marine Geology, vol. 373 pp.55-63, 2016.

[3] T. Kasaya, H. Machiyama, K. Kitada, and K. Nakamura, "Trial exploration for hydrothermal activity using acoustic measurements at the North Iheya Knoll," Geochemical Journal, vol. 49(6), pp.597-602, 2015.

[4] C. R. German, M. V. Jakuba, J. C. Kinsey, J. Partan, S. Suman, A. Belani, and D. R. Yoerger, “A long term vision for long-range ship-free deep ocean operations: persistent presence through coordination of ASVs and AUVs,” Autonomous Underwater Vehicles (AUV) 2012 IEEE/OES, pp.1-7, Southampton, U.K., Sept. 2012

[5] T. Nakatani, T. Hyakudome, T. Sawa, Y. Nakano, Y. Watanabe, T. Fukuda, H. Matsumoto, R. Suga, and H. Yoshida, "Development of an autonomous surface vehicle for monitoring underwater vehicles," OCEANS2015-MTS/IEEE, pp1-5, Washington D.C., USA, Oct. 2015.

[6] Cabinet office, Govenment of Japan,"What is the Cross-ministerial Strategic Innovation Promotion Program?"

http://www8.cao.go.jp/cstp/panhu/sip_english/5-8.pdf

[7] Y. Hirakawa, T. Yoda, T. Takayama, T. Hyakudome and T. Nakatani, “Motion compensator for acoustic device mounted on autonomous surface vehicle,” OCEANS2015-MTS/IEEE, pp.1-4, Washington D.C., USA, 2015.