Successful Repeated Docking under Fluctuating Current Disturbances in Real Sea*

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***Abstract*—To extend the persistence time of an underwater operation of Autonomous Underwater Vehicles(AUVs) in the sea, many studies have been performed worldwide. The docking function takes place as an important role not only for battery recharging but also for other advanced applications. In the previous studies, the repeated sea docking using a Remotely Operated Vehicle(ROV) was succeeded. However, during the experiment in the sea, ROV sometimes failed the docking due to the ocean current disturbance since ROV is hard to correct large error of orientation around z-axis. Therefore, we develop an autonomous rotary station that defects the ocean current direction for correcting the error between the ocean current direction and the docking direction. This paper presents the details of an autonomous rotary station and the analysis of the repeated sea docking experimental result .**

***Index Terms*—Docking, Ocean current, Error, Autonomous rotary station**

I. Introduction

Nowadays, various underwater robots have been researched and developed for seabed searches such as resource excavation and geographical environmental research. Especially, Autonomous Underwater Vehicles(AUVs) play an important role in deep sea works. These works can be made more effective for long-term continuous operation of AUVs. However, the operation time of AUVs is still limited. To solve this problem, underwater battery recharging with a docking system to the charging station is one of the solutions to extend operation time of AUVs.

Most of the studies related to vision based navigation for underwater vehicle are based on single camera[1][2]. Apart from them, we have been studying a stereo-vision based docking approach for an AUV. In our approach, the relative pose between the AUV and a 3D marker is estimated by using Real-time Multi-step Genetic Algorithm (RM-GA) that is a real-time 3D pose estimation method. Avoiding the disadvantages of dual eyes 3D perception by 2D-to-3D reconstruction based recognition methods, we proposed and developed a 3D model based matching method based on 3D-to-2D projection. One of the main drawbacks of 2D-to-3D reconstruction is that incorrect mapping between corresponding points in images, resulting in erroneous pose estimation.

In our previous studies, the repeated sea docking using a Remotely Operated Vehicle (ROV) was succeeded. However, the ROV sometimes failed the docking due to the ocean current disturbance since it is hard for the ROV to correct large error of a yaw rotation. As the ocean current direction changes, the docking direction needs to be aligned to the ocean current direction. Therefore, we develop an autonomous rotary station that detects the ocean current direction for correcting the error between the ocean current direction and the docking direction.

This paper is organized as follows: Section II describes detail of the autonomous rotary station and mechanism of operation. Section III describes the result and discussion of Visual Servo experiment to confirm the system of the autonomous rotary station by using it. Section IV describes the result and discussion about docking experiment in the sea. The final section concludes the paper.

II. DETAIL OF THE AUTONOMOUS ROTARY STATION AND OPERATION MECHANISM

A. The Problem of Conventional Docking System

As ROV sometimes failed the docking due to the ocean current disturbance, it is hard for ROV to correct large error of orientation around z-axis. For solving this problem, we considered that the docking direction needs to be aligned to the ocean current direction. Therefore, we develop an autonomous rotary station that detects the ocean current direction for correcting the error between the ocean current direction and the docking direction. Figure 1 shows the operation image of the rotary station.

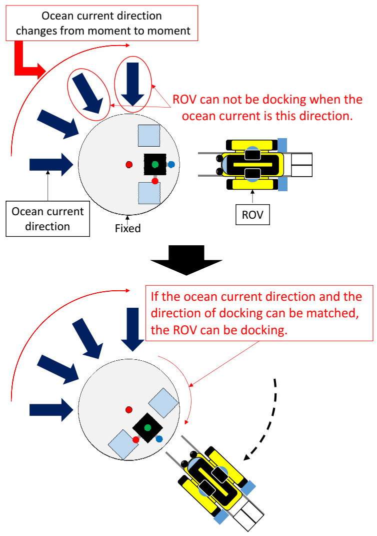

Fig. 1. Operation image of an autonomous rotary station

B. *The Detail of Rotary Station Structure*

Fig. 2 shows the rotary station and rotary table composed of the acrylic plate and attached to two docking holes and the 3D marker. The full length of the rotary station is 3700 [mm], height from ground to the rotary table can be adjusted from 400 [mm] to 700 [mm]. In this rotary station, there are four cameras for recording the ROV operation during the docking experiment and the rotary table, the current sensor for attaching fin which plays a role in defecting the ocean current direction. In addition, there are encoder, motor, decelerator and DA converter at the top of this rotary station. the Encoder shown in Fig. 3 measures the fin rotation angle and the motor rotates the rotary table by the measured angle. Figure 4 shows a flow chart of the rotary station.

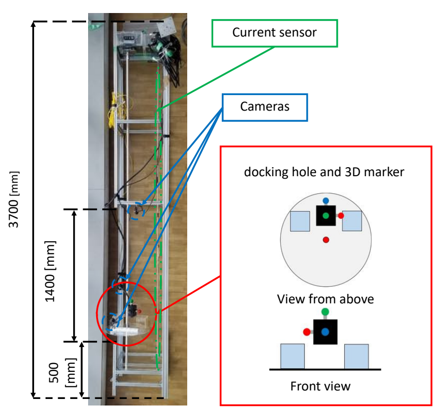

Fig. 2. Overall view of an autonomous rotary station

Figure 5 shows a fin for detecting the ocean current direction. Some plastic bottles are attached to both sides of a acrylic plate for getting the torque from the weak ocean current. The Fin rotates influence of the ocean current, the rotary table rotates the amount of the rotate angle of the fin.

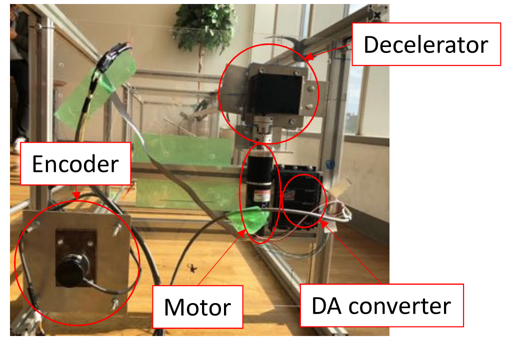

Fig. 3. Structure at the top of an autonomous rotary station

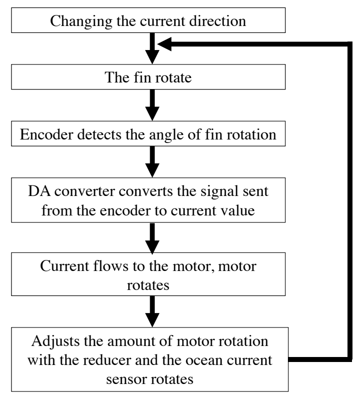

Fig. 4. Flowchart of an autonomous rotary docking station

III. EXPERIMENT FOR CONFIRMING OPERATION OF THE AUTONOMOUS ROTARY STATION

A. *Environment of The Experiment*

In this section, we conducted a Visual Servo(VS) experiment using the autonomous rotary station. Figures 6 and 7 show the experimental environment and ROV. Table I shows a specification of the ROV. In this experiment, we rotated the current sensor by hand for confirming our VS capability.

In this experiment, we used the half size of the autonomous rotary station (pool station) shown in Fig. 8. The system structure of the pool station is same as the autonomous rotary station.

During VS experiment, we rotated the current sensor 15 [degree] clockwise, next 15 [degree] counterclockwise and 30 [degree] clockwise. Figure 9 shows that flow of experiment.

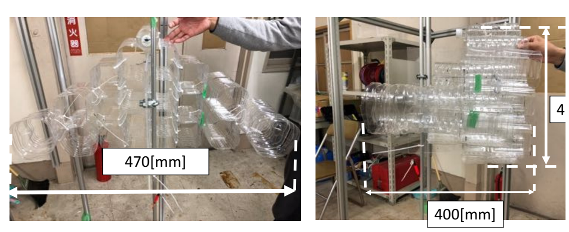

Fig. 5. The fin

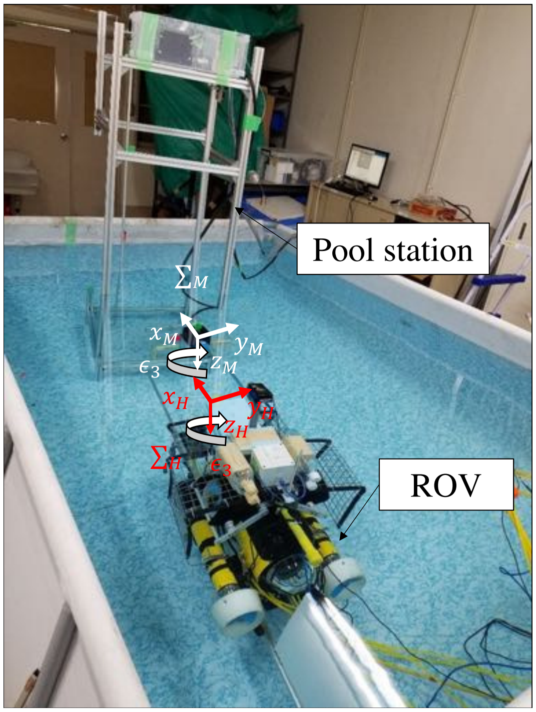

Fig. 6. Experiment Layout

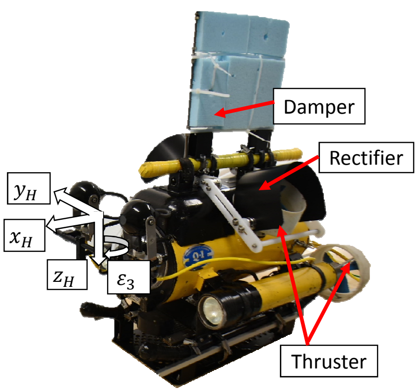

Fig. 7. Overview of DELTA-150

Furthermore, we determined the desired value of the VS. The values of x, y and z are 600 [mm], 0 [mm] and -60 [mm], respectively.

B. The Result of Experiment

Figure 10 shows the experimental result. The timing from (1) to (4) in Fig. 10 is same that the timing of turning the current sensor under experimental conditions. In Fig. 10 [A], the estimated value of x-axis is not so large change. Therefore, this direction is not affected much for rotating by the pool station. In Fig. 10 [C], the desired value of z-axis is -60 [mm], though the recognition error between the desired value and estimated value is about -20 [mm]. On the other hand, there are the large changes in y-axis and the orientation around z-axis (yaw orientation). In the timing (1), after the errors of the y-axis and yaw orientation occurred instantaneously, the estimated value gradually converged at the the desired value. In the timing (2), the estimated value also gradually converged to the the desired value. However, ROV took time to converge the estimated value to desired value since there is the influence of the the cable tension of ROV. In addition, when the pool station rotated about 30 [degree] in timing (4), the estimated value did not converge to desired value and the error between estimated value and desired value was increasing. On the other hand, about orientation around z-axis, the estimated value converged to desired value quickly at the timing from (1) to(4) in the yaw orientation. From these results, our VS has enough capability to the autonomous rotary station.

TABLE I
SPECIFICATION OF QI ROV

Maximum operating depth [m]	150
Dimension [mm]	450(W) × 600(L) × 395(H)
Dry weight [kg]	20
Number of Thrusters	2(Horizontal),2(Vertical and Traverse)
Number of Cameras	3(Front)
Maximum thrust force [N]	30(Horizontal,Vertical and Traverse)

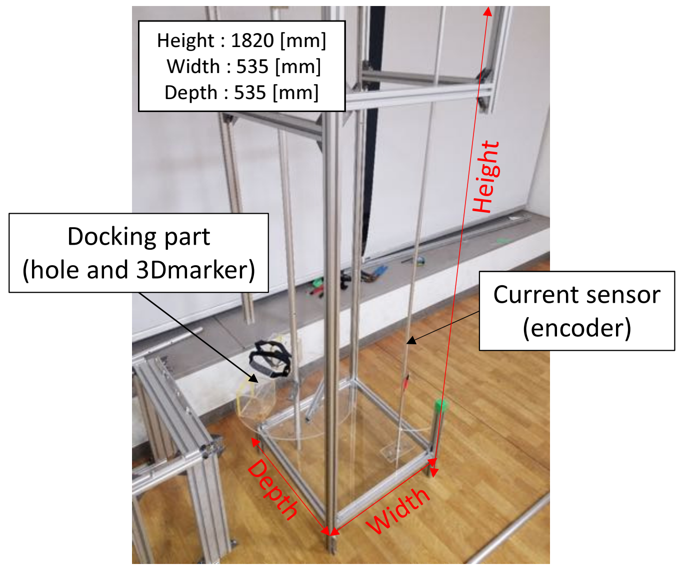

Fig. 8. The Autonomous Rotary Station for Pool

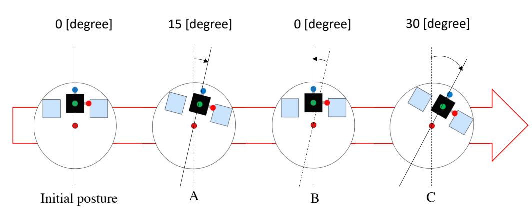

Fig. 9. The image of the visual servo experiment

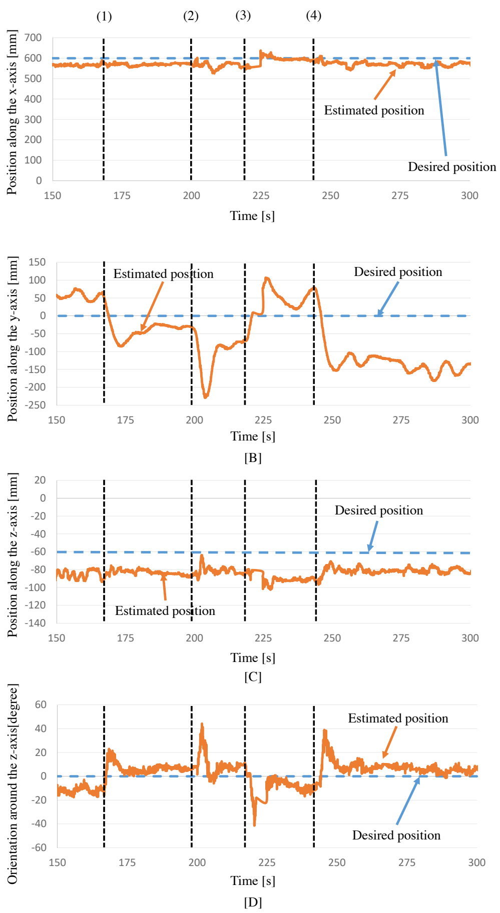

Fig. 10. Experimental result of VS against the autonomous rotary station.

IV. DOCKING EXPERIMENT IN THE SEA BY USING THE AUTONOMOUS ROTARY STATION

A. Environment of The Experiment

Figure 11 shows the experimental environment. In the sea, we conducted the experiment if ROV was enable to completed the docking operation by using the rotary docking station. The rotary station was placed about 1 [m] away from the pier. Table II shows Condition to transition to docking operation and Sea Environment.

TABLE II
CONDITION TO TRANSITION TO DOCKING OPERATION AND SEA ENVIRONMENT

Conditions each of parameters	x coordinate [mm]	350
	y coordinate [mm]	-30~30
	z coordinate [mm]	-80~-20
	coordinate [degree]	-9.99~9.99
Sea Environment	Turbidity [FTU]	2.2
	Illuminance [Lx]	12000
	Depth of water [m]	2.0

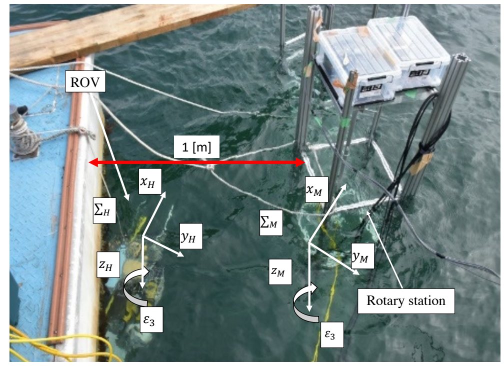

Fig. 11. The Environment of The Docking Experiment in The Sea

B. Experiment Result

Figure 12 shows the one part of the docking experiment result in the sea. From 2200 [s] to 2240 [s], the previous docking operation has ended and the ROV returned to the inital position (x_d = 600 [mm]). At the same time, the angle detected by the encoder changed greatly (Fig. 12 [E]) since the ocean current direction changed greatly. The estimated positions of y and z is near to allowance error area. However, ROV could not start the docking operation instantly since ROV could not correct the error of the yaw orientation due to the ocean current . Then, the rotary station aligned the docking direction to the ocean current direction, and ROV started to correct the error of the yaw orientation. ROV filled the conditions to transition to docking operation at about 2323 [s], and ROV started to move forward slowly from that time (Fig. 12 [A]). Therefore, the average of the estimated poses in the yaw orientation from 2318 [s] to 2323 [s] and from 2313 [s] to 2318 [s] are 9.26 [degree] and 12.31 [degree], respectively. In Table II, ROV corrected the error of the yaw orientation gradually. As the result, ROV completed the docking operation by changing the docking direction. In this way, our proposed autonomous rotary station is effectiveness for the fluctuating ocean current disturbance.

V. CONCLUSION

In this paper, we developed the autonomous rotary station for correcting the error between the ocean current direction and the docking direction. Next, we conducted the docking experiment using the autonomous rotary station for verifying the autonomous rotary station capability. The experiment was succeeded in the real sea.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] Agbakwuru J. "Oil/Gas Pipeline Leak Inspection and Repair in Underwater Poor Visibility Conditions: Challenges and Perspectives," Journal of Environmental Protection, 2012.

[2] Krupi ski, S., Allibert, G., Hua, M.D. and Hamel, T., ”Pipeline tracking for fully-actuated autonomous underwater vehicle using visual servo control,” In American Control Conference (ACC),pp.6196-6202. IEEE, 2012.

[3] Eustice, R.M., Pizarro, O. and Singh, H., Visually augmented navigation for autonomous underwater vehicles, IEEE Journal of Oceanic Engineering, 33(2), pp.103-122, 2008.

[4] Jung, J., Choi, S., Choi, H.T. and Myung, H., Localization of AUVs using depth information of underwater structures from a monocular camera, In Ubiquitous Robots and Ambient Intelligence (URAI), 2016 13th International Conference, pp. 444-446, IEEE, 2016.

[5] Ghosh, S., Ray, R., Vadali, SR., Shome, SN., Nandy, S, Reliable pose estimation of underwater dock using single camera: a scene invariant approach,” Machine Vision and Applications, 27(2), pp. 221-36, 2016.

[6] Kume, A., Maki, T., Sakamaki, T. and Ura, T., A method for obtaining high-coverage 3D images of rough seafloor using AUV-realtime quality evaluation and path-planning, Journal of Robotics and Mechatronics, 25(2), pp.364-374, 2013.

[7] Ribas D, Palomeras N, Ridao P, Carreras M, Mallios A, Girona 500 auv: From survey to intervention, IEEE/ASME Transactions on Mechatronics 17(1), pp.46-53 (2012)

[8] Xiang Li, Yuya Nishida, Myo Myint, Kenta Yonemori, Naoki Mukada, Khin Nwe Lwin, Matsuno Takayuki, Mamoru Minami,”Dual-eyes Vision-based Docking Experiment of AUV for Sea Bottom Battery Recharging,” MTS/IEEE OCEANS’ 17, Aberdeen Scotland, June 19-22, 2017.

[9] Daiki Yamada, Naoki Mukada, Myo Myint, Khin Nwe Lwin, Takayuki Matsuno, Mamoru Minami, ”Improvement of 3D-Pose Real-time Estimation by Active Marker and HSV-evaluated Function,” 23rd International Symposium on Artificial Life and Robotics, B-Con Plaza Beppu, January 18-20, 2018

[10] Myint M, Yonemori K, Lwin K N, Yanou A, Minami M(2017) Dual-eyes Vision-based Docking System for Autonomous Underwater Vehicle: an Approach and Experiments, J Intell Robot Syst , DOI 10.1007/s10846-017-0703-6

[11] Yu F, Minami M, Song W, Zhu J, Yanou A, On-line head pose estimation with binocular hand-eye robot based on evolutionary model-based matching, Journal of Computer and Information Technology, 2(1), pp.43-54, 2012.

[12] Song, W., Minami, M. and Aoyagi, S., Feedforward on-line pose evolutionary recognition based on quaternion. Journal of the Robot Society of Japan, 28(1), pp. 55-64, 2010.

[13] Daiki Yamada, Naoki Mukada, Myo Myint, Khin Nwe Lwin, Takayuki Matsuno, Mamoru Minami, ”Docking Experiment in Dark Environments Using Active/Lighting Marker and HSV Correlation,” MTS/IEEE OCEANS’ 18, Kobe Japan, May 28-31, 2018.

[14] Song W, Fujia Y, Minami M, 3D visual servoing by feedforward evolutionary recognition, Journal of Advanced Mechanical Design, Systems, and Manufacturing, 4(4), pp.739-755, 2010.

[15] Suzuki H, Minami M, Visual servoing to catch fish using global/local GA search, IEEE/ASME Transactions on Mechatronics, 10(3), pp.352-357, 2005.

[16] Kenta Yonemori, Myo Mynt, Mamoru Minami, Naoki Mukada, Khin Nwe, Sea Docking Experiment with Vision-based Recognition Using Dual eye Camera, 22st International Symposium on Artificial Life and Robotics, B-con Plaza Beppu, January 19-21, 2017

[17] Xiang Li, Yuya Nishida, Myo Myint, Kenta Yonemori, Naoki Mukada, Khin Nwe Lwin, Matsuno Takayuki, Mamoru Minami, Dual-eyes Vision based Docking Experiment of AUV for Sea Bottom Battery Recharging, MTS/IEEEOCEANS2017,Aberdeen Scotland, June 19-22, 2017

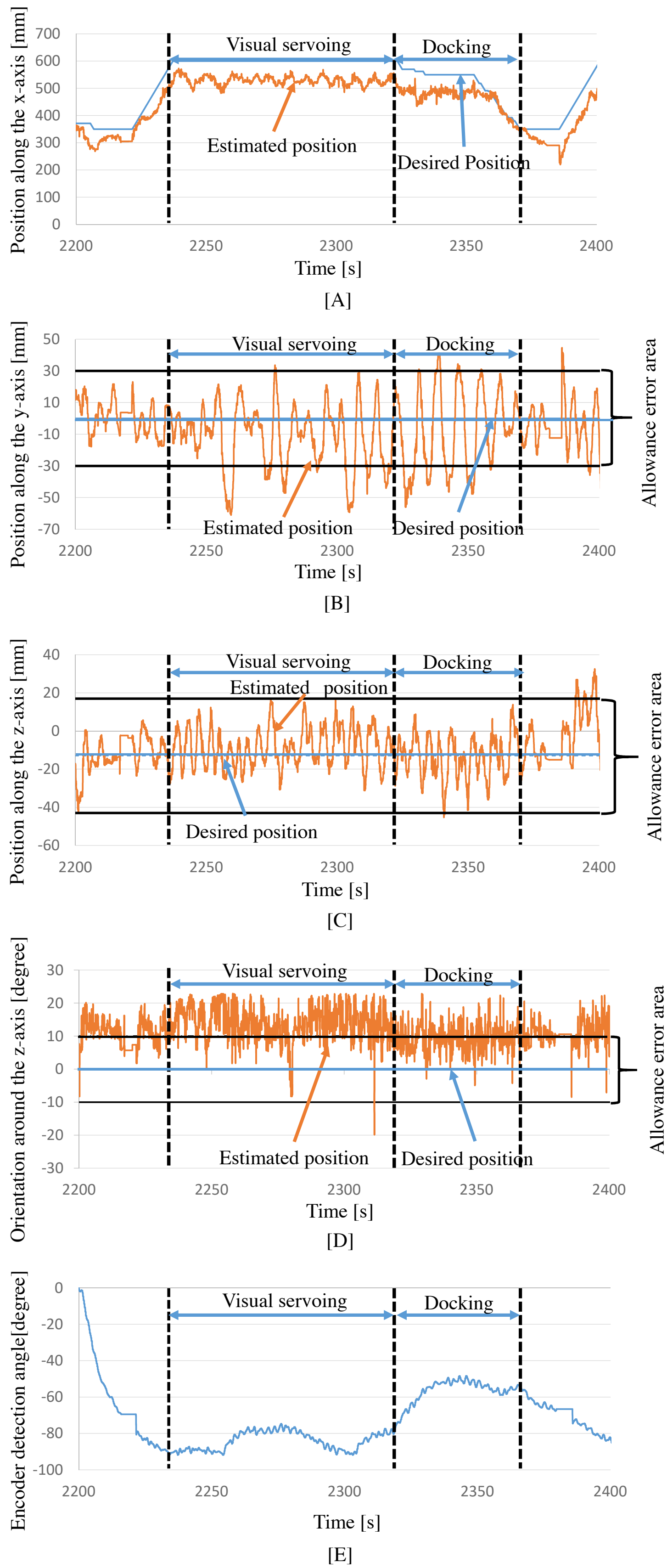

Fig. 12. Docking Result Against The Rotary Station: (A) Position along The X-axis, (B) Position along The Y-axis, (C) Position along The Z-axis, (D) Orientation around The Z-axis, (E) The Encoder detects Angle