Dual-eyes Vision-based Docking Experiment of AUV for Sea Bottom Battery Recharging

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***Abstract*—This paper presents docking experiments for AUV using stereo vision for sea bottom battery recharging application. Real-time 3D pose tracking system was installed in AUV "Tuna-Sand 2". Underwater battery recharging unit with unidirectional docking function was simulated in indoor pool. Tuna-Sand 2 approached to the docking station using other sensors and docking operation was performed by visual servoing when a 3D marker was detected. Experimental results showed the performance of the proposed system with accurate docking accuracy in a short time.**

I. Introduction

To extend the duration of underwater operation of AUVs, nowadays, many studies has being performed worldwide. Among them, underwater battery recharging technology is one of the solutions even through challenges are still remained. Therefore, docking function takes place as an important role not only for battery recharging but also for other advanced applications such as intervention using some manipulators. Generally there are three steps in docking operation; (1) long distance navigation step, (2) approaching step, and (3) final docking step. There are many kinds of approaches for docking operation using different sensors and techniques [1]-[11]. However, final docking step is a critical task when accurate homing accuracy and robustness against different disturbances are dominant. Normally, catching AUVs has been conducted by using big net mechanisms with appropriate homing accuracy. However, this kind of technique can occur any physical damage to AUVs as well as docking station. To overcome this limitation, we have developed dual eyes vision-based docking system especially for final docking step.

In our previous works [12]-[14], we conducted different experiments to confirm the robustness of our vision-based docking system using two cameras and known 3D marker. Then we conducted sea trial docking using small ROV as a test bed successfully [15]. With some improvements in proposed system, our next step is to apply our system in AUV to confirm the performance of vision-based docking system. Therefore, this paper describes vision-based docking experiment of AUV using two cameras and 3D marker. Hovering type AUV "Tuna-Sand 2" as shown in Fig.1 which can dive up to 2,000 m depth and move five degree of freedom was facilitated with two cameras and GA PC in which vision-based real time 3D pose tracking was implemented. We conducted docking experiment in indoor pool simulated for sea bottom battery recharging application.

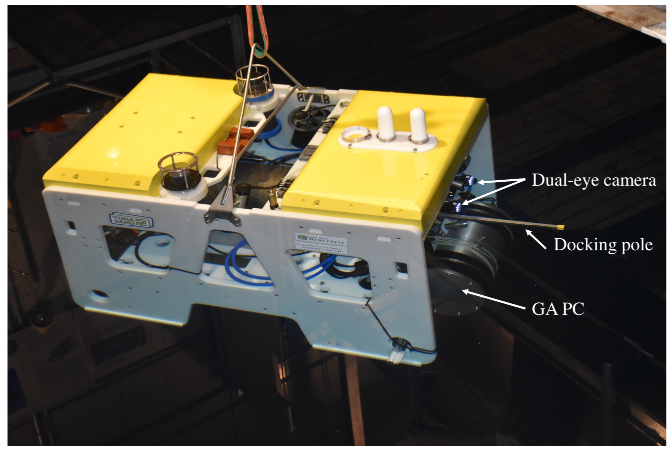

Fig. 1. Dual eyes vision-based docking system in Tuna-Sand 2

This paper is organized as follows: Section II presents the dual eyes vision-based real-time 3D pose tracking. Section III describes experimental environment. Section IV describes results and discussion respectively. The final section contains the conclusion and further work.

II. Dual eyes vision based real time 3D pose tracking

Figure.2 shows the block diagram of proposed system. Images from dual-eye camera installed on Tuna-Sand 2 are sent to the GA PC. Real-time pose estimation using 3D model based matching method and real-time multi-step GA is implemented as software implementation in GA PC. Based on the real time relative pose estimation between AUV and docking station, and docking strategy, GA PC sends command signals to the Tuna-Sand 2 CPU through TCP/IP communication.

A. Real time 3D pose estimation

Real time 3D pose estimation using 3D model-based recognition and real-time multi-step GA was presented in detail in previous paper [16]. The main task is to search the best model with appropriate pose that is strongly correlated with real 3D marker. Figure.3 shows the flowchart of real-time multi-step

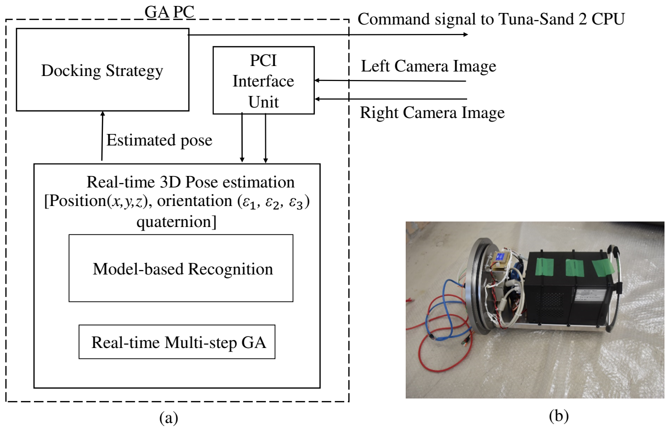

Fig. 2. (a) Block diagram of the proposed System and (b) Photo of GA PC

GA and how the best model is searched. Real time pose is estimated for every image with image frame rate of 33 ms. Please note that recognition and convergence are done in 3D space and evaluation is performed in 2D images.

B. Docking Strategy

Docking procedure including three steps is shown in Fig.4.

1) Approaching step: In this step, AUV approaches to the docking station until 3D marker is detected. Long navigation using other sensors such as acoustic sensors can be performed. Instead of approaching using these sensors, in this experiment, AUV approaches to the station by following preset way points using other sensors such as DVL and depth sensor.

2) Visual servoing step: When AUV detects 3D marker using two cameras, controlling AUV by Tuna-Sand 2 CPU to follow way points is switched to controlling AUV by means of visual servoing. GA PC in which real-time pose estimation using 3D model-based matching method and real-time multi-step GA was implemented performs visual servoing step by giving command signals to Tuna-Sand 2's CPU to follow the desired pose.

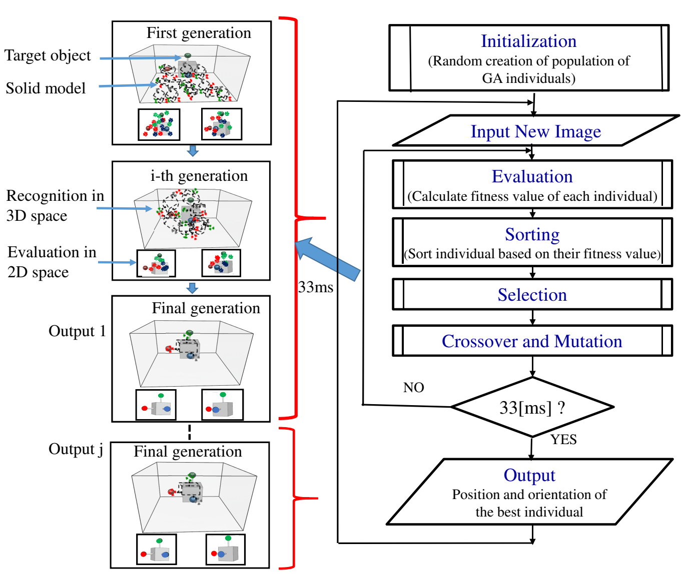

Fig. 3. Pose estimation using real-time multi-step GA

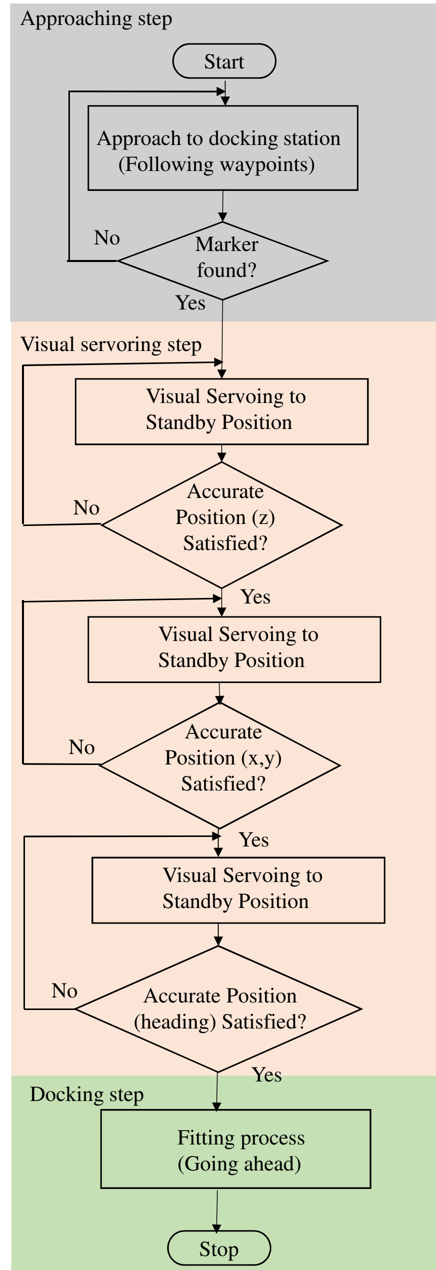

Fig. 4. Flowchart of Docking Strategy

3) Docking step: Docking step is started when the AUV is stable at the entry point for docking within defined allowance position error range. In this step, AUV moves ahead to insert docking pole into the docking hole by reducing distance between AUV and 3D marker. After finished docking step, recorded data are stored by GA PC and AUV returns back to the surface of the pool.

III. Experimental Environment

A. Autonomous Underwater Vehicle "Tuna-Sand 2"

Hovering type Tuna-Sand 2 as shown in Fig.5 is used as a test bed. There are basically four instrument devices including obstacle detection, 3D mapping device, sampling

Fig. 5. Photo of Tuna-Sand 2 with GA PC and dual-eye camera

device and profiling sonar in Tuna-Sand 2 [17]. To conduct vision-based docking experiments, two fixed cameras and GA PC are installed at the front of the vehicle for real time pose tracking. To demonstrate battery recharging, docking pole is attached in AUV as shown in Fig.5. The coordinate systems of AUV and 3D marker are shown in Fig.6.

TABLE I. KEY FEATURES OF TUNA-SAND 2

Dimension [m]	1.4 (W) × 1.2 (L) × 1.3 (H)
Weight [kg]	380
Max. depth [m]	2,000
Max. duration [h]	8
Thrusters	4 (Horizontal thruster), 2 (Vertical thruster)
Sensors	INS, DVL, Depth Sensor, USBL, Cameras

B. Docking Station

Docking station that is unidirectional type was designed to demonstrate sea underwater battery recharging as shown in Fig.7. The size of the docking station is 60 cm × 45 cm × 300 cm. To check the performance of the docking of AUV, underwater cameras are installed in docking station to record. Docking station is fixed in indoor pool.

IV. RESULT AND DISCUSSION

We conducted docking operation in indoor pool. Firstly, communication between GA PC and Tuna-Sand 2's CPU using TCP/IP protocol was confirmed in transferring estimated real-time pose and command signals. Controlling AUV in surface and monitoring the performance of AUV using wireless

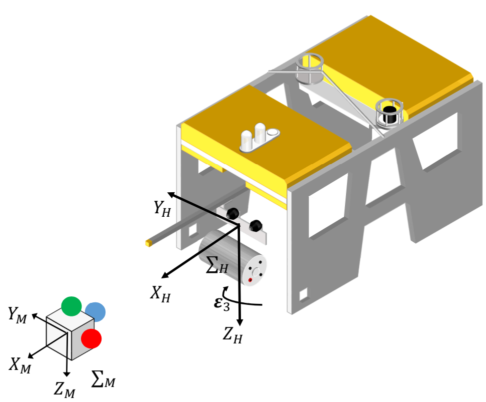

Fig. 6. Coordinate system in AUV and 3D marker

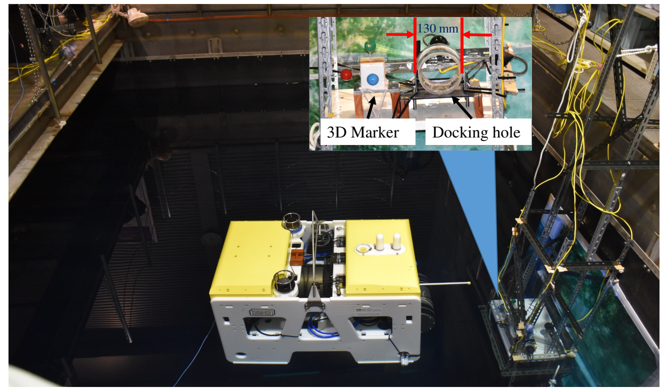

Fig. 7. Docking station with 3D marker

communication was confirmed before docking operation in depth. Recorded log in files were stored in GA PC during operation and download and analyzed after AUV's return to surface. Finally, fully automatically docking experiment was conducted successfully.

A. Approaching to the station following preset waypoints

In the first step, AUV followed the preset way points to approach the station until 3D marker was detected by two cameras. Figure.8 shows trajectory of AUV following predefined path from P0 to P9 in order. When AUV reached P9, 3D marker was detected and AUV was controlled automatically by vision-based pose tracking system. During approaching step, AUV was controlled using DVL data and depth sensor data to follow preset path.

B. Visual servoing and docking step

When AUV approached to the station and 3D marker was in the field of view of two cameras, AUV switched from

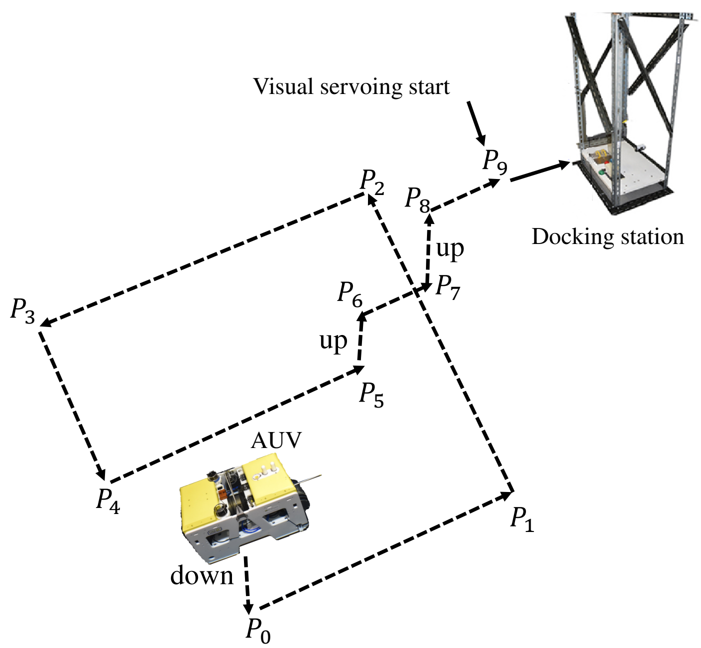

Fig. 8. Trajectory of AUV following predefined path

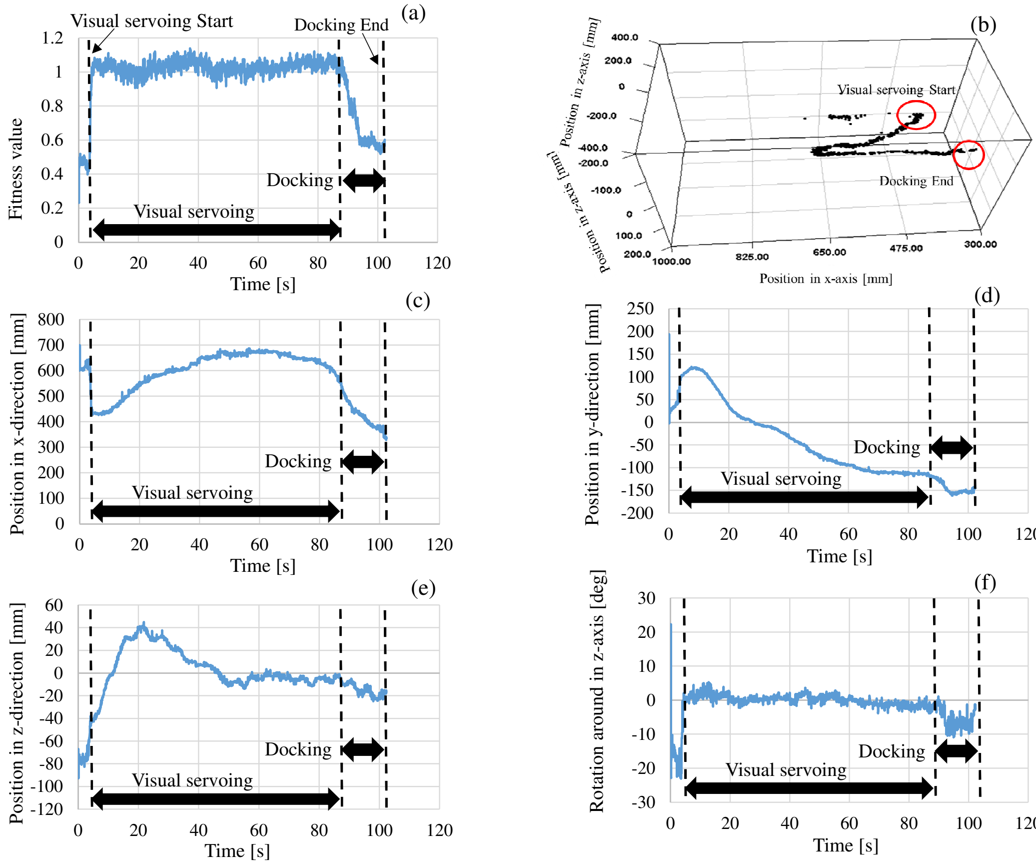

Fig. 9. Docking performance : (a) fitness value, (b) 3D trajectory, ((c)-(e)) recognized positions in x,y,z axis direction and (f) rotation around z-axis direction

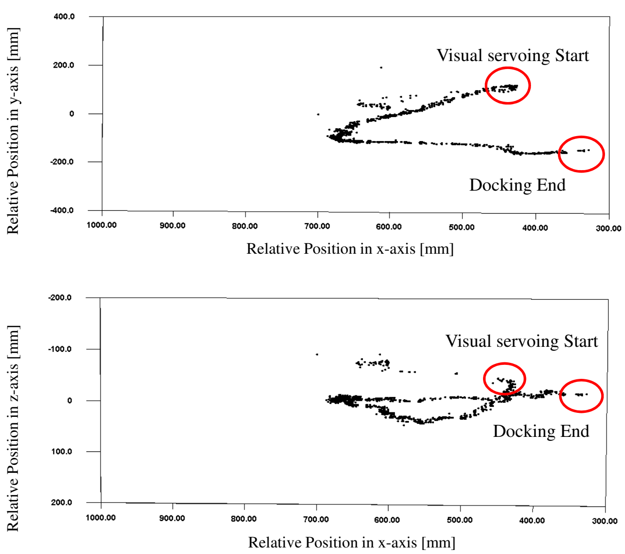

Fig. 10. Trajectory of AUV during visual servoing and docking

approaching step to visual servoing step. In visual servoing step, the AUV moved to the entry point for docking that is defined by the following relative pose:

$$x_d = {}^H x_M = 600[mm],$$
$$y_d = {}^H y_M = -78[mm],$$
$$z_d = {}^H z_M = 0[mm], \quad \epsilon_{3d} = 0[deg]$$

When the AUV was stabled at the entry point with allowance position error for defined period, it switched from visual servoing step to docking step in which the vehicle moved ahead to insert docking pole into the docking hole precisely. Fig.9 shows the docking performance of AUV. When the AUV approached to the station, 3D marker detection was checked by means of fitness value that is 0.5 in this experiment. Therefore, when fitness value is above 0.5, visual servoing step was started as shown in Fig.9.(a). Figure.9.(b) shows the 3D trajectory of AUV recognized by proposed system. Start point means where the AUV arrived at P9 in Fig.10 and End point is the position where docking step is finished successfully. When the AUV was at entry point and stable within allowance position error, docking step was performed by reducing distance of 200 mm in x-axis direction as shown in Fig.9.(c). Figures 9.(d)-(f) shows recognized positions in y,z axis direction and rotation around z-axis direction. According to experimental result, docking operation was performed successfully within 2 minutes. Figure.10 shows trajectory of AUV during visual servoing and docking step in 2D. After docking end, the GA PC stored log in files from memory into hard disk and the AUV returned back to the surface.

V. Conclusion

In this paper, dual-eyes vision-based docking experiment of AUV for sea bottom underwater battery recharging application is described. Tuna-Sand 2 was facilitated with vision-based 3D pose tracking system using two cameras. Sea bottom battery recharging using docking function was simulated in indoor pool. In approaching step, Tuna-Sand 2 AUV approached to the docking station following predefined way points using other navigation sensors such as DVL and depth sensor. For final step of docking step, AUV was controlled automatically using vision information from two cameras. Experimental results confirmed the performance of 3D recognition and docking with accurate accuracy. In future work, the proposed system will be developed for real sea environment and sea trail docking of AUV using proposed system will be conducted for underwater battery recharging.

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