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Position and attitude control of underwater vehicle-manipulator systems using a stereovision system

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Abstract: Underwater Vehicle-Manipulator Systems (UVMS) are expected to make important roles in ocean exploration. The manipulator operations in underwater need information of position between an object of capture and the vehicle. Therefore, sensors that measure position and attitude of the objects must be mounted on UVMS. We have been developing a stereovision system for UVMS. In this paper, to verify the effectiveness of the proposed stereovision system equipped to a floating UVMS, experiments on position and attitude control of the UVMS are done.

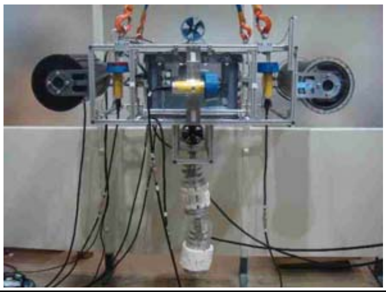
Keywords: Underwater Robot, Manipulator, Stereovision System

1 Introduction

Underwater robots are expected to make important roles in ocean exploration and many studies on Underwater Vehicle-Manipulator Systems (UVMS) are performed in recent years [1–5]. However there are only a few experimental studies. We have proposed digital Resolved Acceleration Control (RAC) methods for UVMS [6,7] and the effectiveness of the RAC methods has been demonstrated by using a floating underwater robot with vertical planar 2-link manipulator.

Here, underwater robots having small size manipulators have been used in real situations. Manipulator operations in underwater need information of position between object of capture and vehicle. Therefore, sensors that measure position and attitude of the objects must be mounted on UVMS.

We have been developing a stereovision system for UVMS. In this paper, to verify the effectiveness of the proposed stereovision system equipped to a floating UVMS, experiments on position and attitude control of the UVMS are done. The experimental results show the effectiveness of the stereovision system.



	Base	Link 1	Link 2
Mass [kg]	104.52	4.65	4.65
Volume [$\times 10^{-3}$ m^3]	108.04	3.3	3.1
Moment of inertia [kgm^2]	2.40	0.075	0.075
Link length (x axis) [m]	0.870	0.35	0.28
Link length (y axis) [m]	0.640	-	-
Link length (z axis) [m]	0.335	-	-
Link diameter[m]	-	0.13	0.13
Added mass(x) [kg]	73.19	0.35	0.35
Added mass(y) [kg]	30.57	3.31	3.31
Added mass(z) [kg]	99.54	3.31	3.31
Added moment of inertia [kgm^2]	1.28	0.06	0.06
Drag coefficient(x)	1.2	0	0
Drag coefficient(y)	1.2	1.0	1.0
Drag coefficient(z)	1.2	1.0	1.0

Fig. 1 2 link underwater robot

2 Configuration of Experimental System

2.1 UVMS

The underwater robot used in this paper is shown in Fig. 1. The robot has a robot base (vehicle) and a 2-link manipulator. By six thrusters equipped in the robot base, three-dimensional movement is possible. In addition, two waterproof cylinders has been equipped on front and rear of the robot. The one of cylinders is for a stereovision system and the other is for balance weights.

2.2 Stereovision system

Fig. 2 shows our developing stereovision system for UVMS. The size of the system is 540×140×136[mm] and the mass is 2.2[kg].

The stereovision system is equipped with two CCD cameras that can pan and tilt individually by

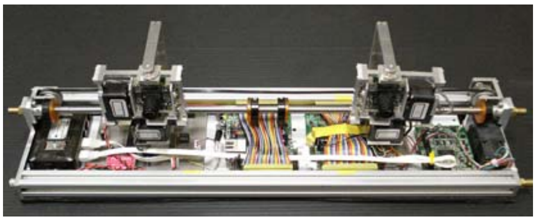


Fig. 2 Stereovision system

Table 1 Motor specification

Axis	Pan, Tilt	Slide
Gear ratio	-	1:10
Torque [kg·cm]	5.0	10
Resolution [deg]	0.2	0.072
Input signal	RS485	PWM

Table 2 Camera specification

Signal system	NTSC 30fps
Scanning system	2:1 interlaced
Picture elements	768(H)×494(V)[pixel]
Clock frequency	28.636[MHz]
Video output	1.0Vp-p/75Ω compositeVBS, digitalYUV

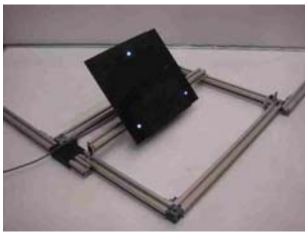


Fig. 3 LED marker

servo actuators. Moreover, the stereovision system has a slide mechanism by one stepping motor; it is possible to vary the distance between the cameras for avoiding occlusions. Table 1 shows specifications of the motors. Moving from side to side two cameras, the stereovision system control pan/tilt angle of the cameras to track the measurement object at the center of image surface. By doing this, the position and attitude can be obtained from that angles and measuring coordinates on the pixel surface of the cameras. the specification of the CCD camera to shoot object is shown in Table 2. In this paper, measurement object is flat object that has three radiants. Fig. 3 shows the LED marker for measurement. The cameras change of each pan/tilt angle to track the centroid of the three radiants.

3 Measurement Method

In this section, we explain the position and attitude measurement method using the stereovision system shown in Fig. 2.

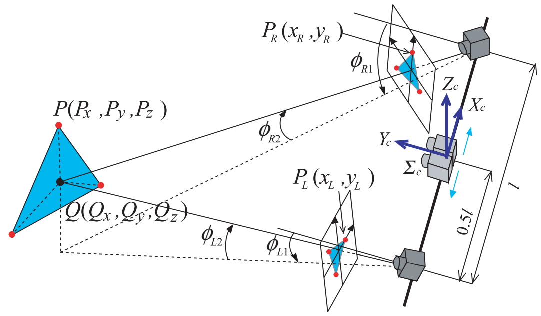


Fig. 4 Measurement model

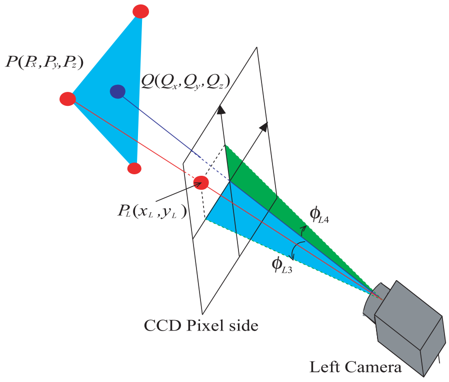


Fig. 5 Camera coordinate system

Fig. 4 shows the measurement model of Fig. 2. From Fig. 4, position of centroid of the object, $Q(q_x,$ $q_y,$ $q_z)$, can be calculated from the geometric relationship as follows:

$$\left.\begin{aligned} q_x &= 0.5l - k\sin\theta_{R_1}, \\ q_y &= k\cos\theta_{R_1}, \\ q_z &= k\tan\theta_{R_2} \end{aligned}\right\} \quad (1)$$

where

$$k = \frac{\cos\theta_{L_1}}{\sin(\theta_{R_1} - \theta_{L_1})} l, \quad \theta_{*_1} = \phi_{*_1}, \quad \theta_{*_2} = \phi_{*_2}.$$

Fig. 5 shows the camera coordinate system of the left camera. In Fig. 5, position of a radiant on the pixel surface is defined as $P_L(x_L,\ y_L)$. In the similar manner, $P_R(x_R,\ y_R)$ for the right camera is also defined. Positions of three radiants $P_i(x_i,\ y_i,\ z_i)$ $(i = 1,\ 2,\ 3)$ are similarly obtained by transforming Eq. (1) as follows:

$$\begin{gathered} \theta_{*_1} = \phi_{*_1} - \phi_{*_3}, \quad \theta_{*_2} = \phi_{*_2} + \phi_{*_4}, \\ \phi_{*_3} = \tan^{-1}\left(\frac{x_*}{f}\right), \quad \phi_{*_4} = \tan^{-1}\left(\frac{y_*}{f}\right) \end{gathered} \quad (2)$$

where f is the focal length. Using $P_i(x_i,\ y_i,\ z_i)$ the normal vector of the plane through three points, $\boldsymbol{m} = [u,\ v,\ w]^T$, can be obtained:

$$\boldsymbol{m} = \begin{bmatrix} (y_2-y_1)(z_3-z_1)-(y_3-y_1)(z_2-z_1) \\ (z_2-z_1)(x_3-x_1)-(z_3-z_1)(x_2-x_1) \\ (x_2-x_1)(y_3-y_1)-(x_3-x_1)(y_2-y_1) \end{bmatrix}. \quad (3)$$

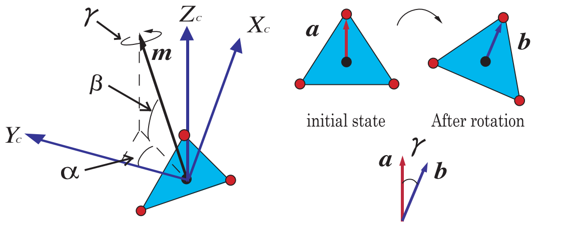


Fig. 6 Attitude

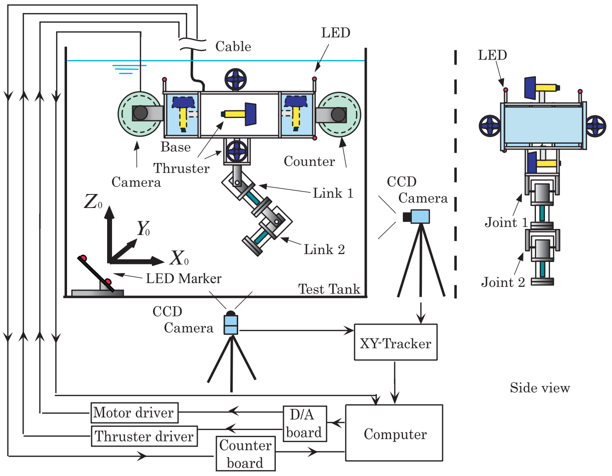


Fig. 7 Configuration of experimental system

The attitude of the measurement object is defined by the angle between the normal vector and the coordinate plane as shown in Fig 6. From Fig 6, attitude angles α and β are described as follows:

$$\alpha = -\mathrm{atan2}\,(u,\ v)\,,\quad \beta = \mathrm{atan2}\left(w,\ \sqrt{u^2+v^2}\right). \tag{4}$$

Moreover, in the initial state, $\boldsymbol{a}$ is defined as vector between Q and P_1, and $\boldsymbol{b}$ is defined as vector between Q and P_1 after rotation. From $\boldsymbol{a}$ and $\boldsymbol{b}$, the third attitude angle γ is described as follows:

$$\gamma = \cos^{-1}\left(\frac{\boldsymbol{a}^T\boldsymbol{b}}{||\boldsymbol{a}||||\boldsymbol{b}||}\right). \tag{5}$$

4 Experiments

In this section, PI control experiments are done to verify the effectiveness of the stereovision system for control of UVMS using the experimental system shown in Fig. 7.

The origin of the inertial coordinate frame is defined to the center of gravity of the LED marker. The LED marker is fixed to the bottom of the water tank. Position and attitude of the UVMS are calculated by measured information of the LED marker obtained from the stereovision system. Also, the pose of UVMS can be obtained by two CCD cameras (XY-Tracker) have been located outside of the tank. We compare the experimental results that controlled by stereovision system with the other controlled by XY-Tracker.

The experiments are carried out under the following condition. Two experimental conditions are the same. The sampling period is T=1/30[s]. The initial position is set up $(X,\ Y,\ Z)$ = (0.4, 0, 0.9)[m] on the inertial coordinate frame and the desired position and attitude of the base is set up $(X,\ Y,\ Z)$ = (0.4, 0, 0.75)[m]. The proportional and integral gains of the controller are $(P_x,\ P_y,\ P_z,\ P_r,\ P_p,\ P_y)$ = (1.0, 1.5, 3, 1, 2, 1) and $(I_x,\ I_y,\ I_z,\ I_r,\ I_p,\ I_y)$ = (0.8, 0.8, 0.9, 0.6, 0.6, 0.4).

Fig. 8 and 9 show experimental results. From results, the stereovision system of the present work similar to XY-Tracker. Therefore, the use of stereovision system to UVMS is considered to be effective.

5 Conclusion

In this paper, we proposed a stereovision system for UVMS. The effectiveness of the proposed stereovision system was demonstrated by using a floating underwater robot. The experimental results show the effectiveness of the stereovision system.

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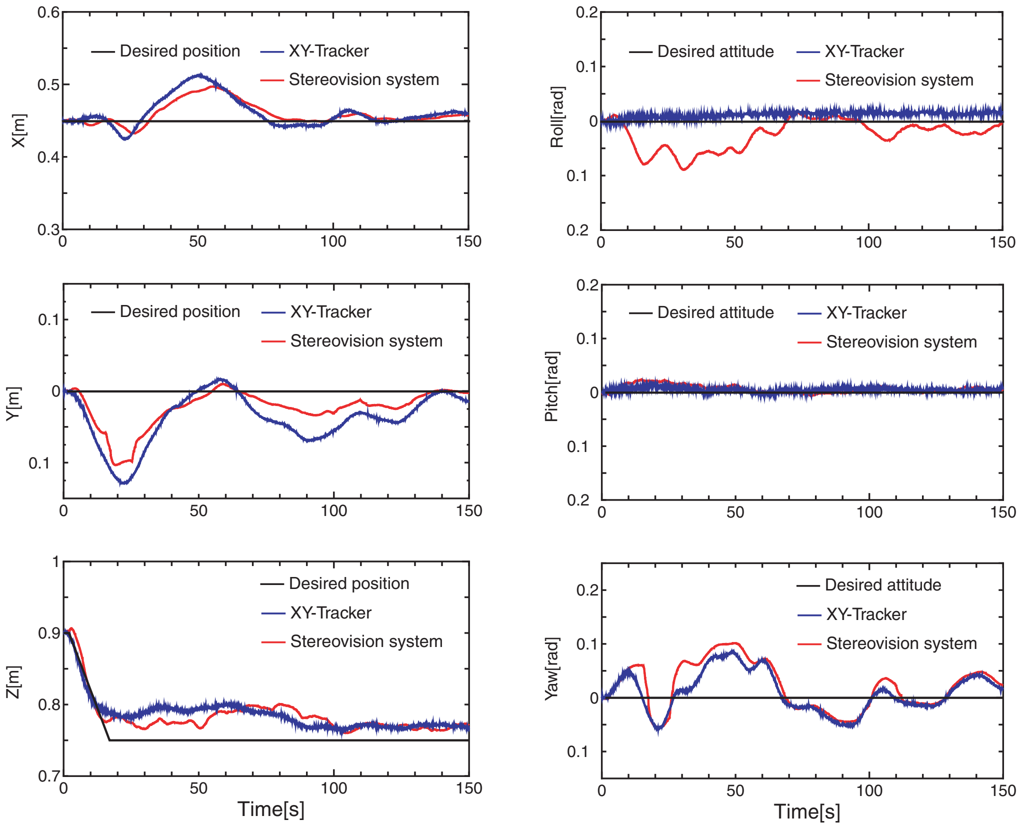

Fig. 8 Experimental result using stereovision system

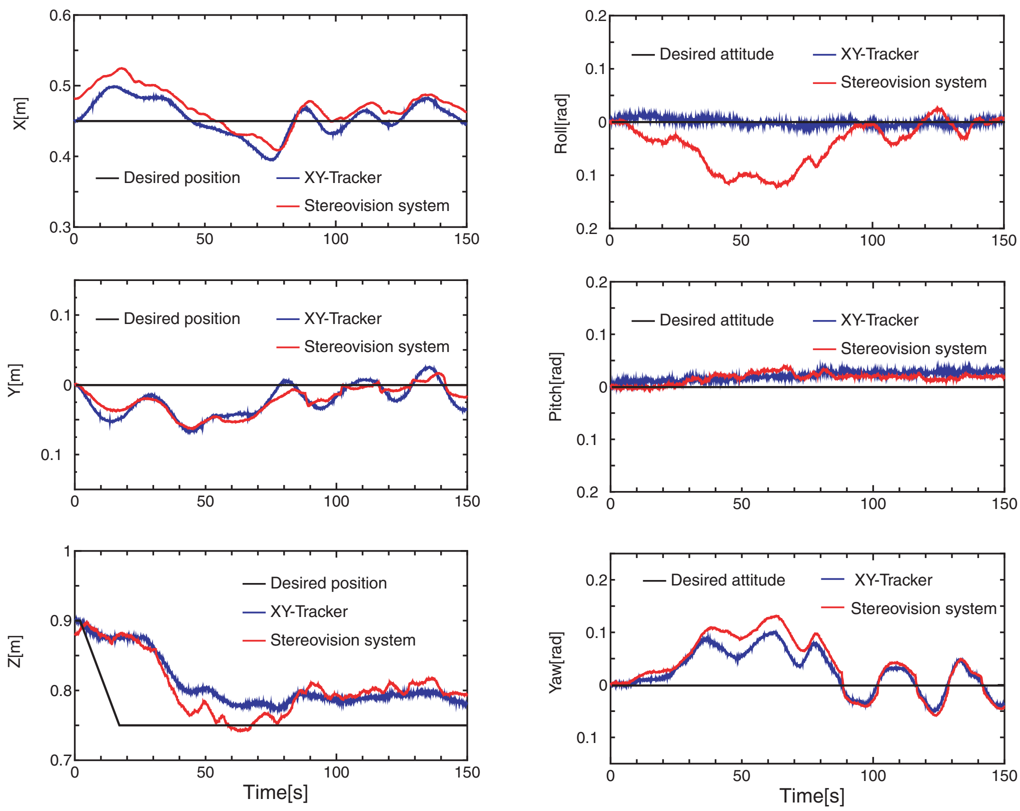

Fig. 9 Experimental result using XY-Tracker