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A Master-Slave Control System for Semi-Autonomous Underwater Vehicle-Manipulator System

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Abstract: Underwater Vehicle-Manipulator Systems (UVMS) are expected to make important roles in ocean exploration. It is considered that UVMSs will be operated by automatic and manual control. We have proposed an automatic control method. In this paper, we propose a master-slave system for UVMS. The effectiveness of the proposed master-slave control systems is demonstrated by using a floating underwater robot with 2-link manipulator.

Keywords: Underwater Robot, Manipulator, Master-Slave Control 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. Since the robots are operated by manual control, it is considered that UVMSs will be operated by automatic and manual control.

In this paper, we propose a master-slave control system for UVMS. The master-slave control system is consisting of the master controllers of the vehicle and the manipulator, and UVMS equipped with the RAC. Our proposed master controller of the vehicle can manipulate only one hand. The effectiveness of the proposed master-slave control systems is demonstrated by using a floating underwater robot with 2-link manipulator.

2 Configuration of Master-Slave Control 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.

Our proposed Resolved Acceleration Control (RAC) method [6] is applied to the control system

	Base	Link 1	Link 2
Mass [kg]	23.05	4.65	4.65
Volume [$\times 10^{-3}$ m^3]	25.95	3.3	3.1
Moment of inertia [kgm^2]	1.67	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]	34.05	0.35	0.35
Added mass(y) [kg]	24.48	3.31	3.31
Added mass(z) [kg]	60.43	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

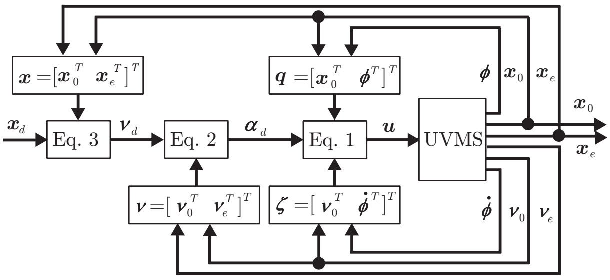

Fig. 2 Configuration of RAC system

of the robot. The RAC method is consisting of the following equations of motion of the robot, desired acceleration and desired velocity:

$$\boldsymbol{u} = \boldsymbol{M}(\boldsymbol{q})\boldsymbol{\alpha}_d + \boldsymbol{N}(\boldsymbol{q},\ \boldsymbol{\zeta})\boldsymbol{\zeta} + \boldsymbol{f} \quad (1)$$

$$\boldsymbol{\alpha}_d(k) = \frac{1}{T}\boldsymbol{W}(k)^{\sharp}\{\boldsymbol{\nu}_d(k+1) - \boldsymbol{\nu}_d(k) + \boldsymbol{\Lambda}\boldsymbol{e}_\nu(k) + T\boldsymbol{f}(k)\} \quad (2)$$

$$\boldsymbol{\nu}_d(k) = \frac{\boldsymbol{S}_{0e}}{T}\{\boldsymbol{x}_d(k) - \boldsymbol{x}_d(k-1) + \boldsymbol{\Gamma}\boldsymbol{e}_x(k-1)\} \quad (3)$$

where for Eq. (1) $\boldsymbol{q} = [\boldsymbol{x}_0^T,\ \boldsymbol{\phi}^T]^T$ and $\boldsymbol{\zeta} = [\dot{\boldsymbol{v}}_0^T,\ \dot{\boldsymbol{\phi}}^T]^T$, $\boldsymbol{x}_0$ is the position and attitude vector of robot base, $\boldsymbol{\phi}$ is the relative joint angle vector, $\boldsymbol{v}_0$ is the linear and angular vector of robot base, $\boldsymbol{M}$ is the inertia matrix including the added mass and inertia, $\boldsymbol{N}(\boldsymbol{q},\boldsymbol{\zeta})\boldsymbol{\zeta}$ is the vector of Coliolis and centrifugal forces, $\boldsymbol{f}$ is the vector consisting of the drag, gravitational and buoyant forces and moments, $\boldsymbol{u} = [\boldsymbol{f}_0^T,\ \boldsymbol{\tau}_0^T, \boldsymbol{\tau}_m^T]^T$, $\boldsymbol{f}_0$ and $\boldsymbol{\tau}_0$ are the force and torque vectors of vehicle, $\boldsymbol{\tau}_m$ is the joint torque vector of manipulator. For Eqs. (2) and (3) $\boldsymbol{e}_\nu(k) = \boldsymbol{\nu}_d(k) - \boldsymbol{\nu}(k)$ and $\boldsymbol{e}_x(k) = \boldsymbol{x}_d(k) - \boldsymbol{x}(k)$, T is a sampling period, $\boldsymbol{S}_{0e}$ is the transformation matrix, and $\boldsymbol{W}^\sharp$ is the pseudoinverse of $\boldsymbol{W}$, i.e. $\boldsymbol{W}^\sharp = \boldsymbol{W}^T(\boldsymbol{W}\boldsymbol{W}^T)^{-1}$, $\boldsymbol{x}_d$ is the desired value of $\boldsymbol{x} = [\boldsymbol{x}_0^T,\ \boldsymbol{x}_e^T]^T$, $\boldsymbol{\Lambda} = \mathrm{diag}\{\lambda_i\}$ and $\boldsymbol{\Gamma} = \mathrm{diag}\{\gamma_i\}$ (i =1, $\cdots$, 12) are the velocity and the position feedback gain matrices.

Fig. 2 shows the configuration of the RAC system.

2.2 Master controller

Fig. 3 shows our developing operating device consisting of base and manipulator operation parts.

The base operating device can perform the operation of 3-DOF potition and 3-DOF attitude with having grasped a rectangular solid in the center of the hemisphere with one hand. At first the roll, pitch and yaw of the rectangular solid which is inclined to the arbitrary direction of the rotational motion is measured by three servo actuators which were arranged so that an axis is perpendicular at the center of rectangular solid. The posture of the rectangular solid can reduce the burden of the manipulator because it is maintained when the operator separated a hand by using the servo actuator. Next, the operator can perform the translational motion by three potentiometer equipped the rectangular solid. It can come true by handling it as translational speed in proportion to displacement (a potential difference) from the center of a lever of the potentiometer.

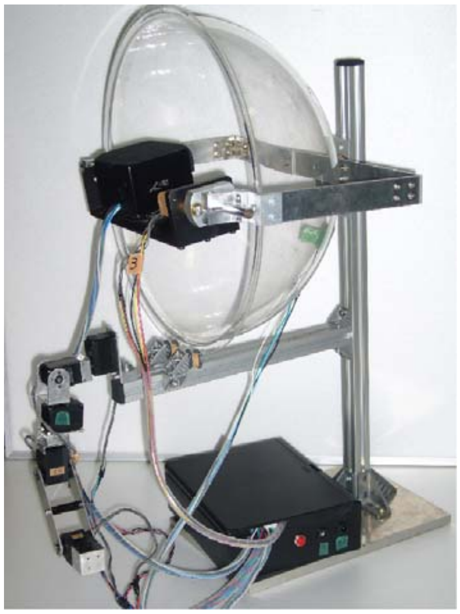
Fig. 3 Master Controller

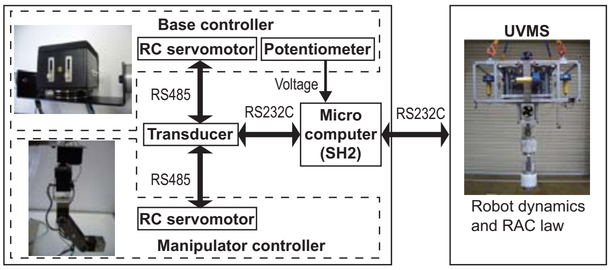

Fig. 4 Configuration of master-slave system

On the other hand, servo actuators are equipped to each joint of the manipulator operation device. The servo actuators are used for the keeping the posture of the manipulator and the obtaining the joint angles.

The configuration of the master-slave control system is shown in Fig. 4. Using the three potentiometers and three servo actuators the desired translational speed and attitude of the robot base are transmitted to the robot base through a microcomputer. In the similar manner, using the two servo actuators the desired joint angles are transmitted to the manipulator. The transmission rate between the microcomputer and the robot is 115200[bps].

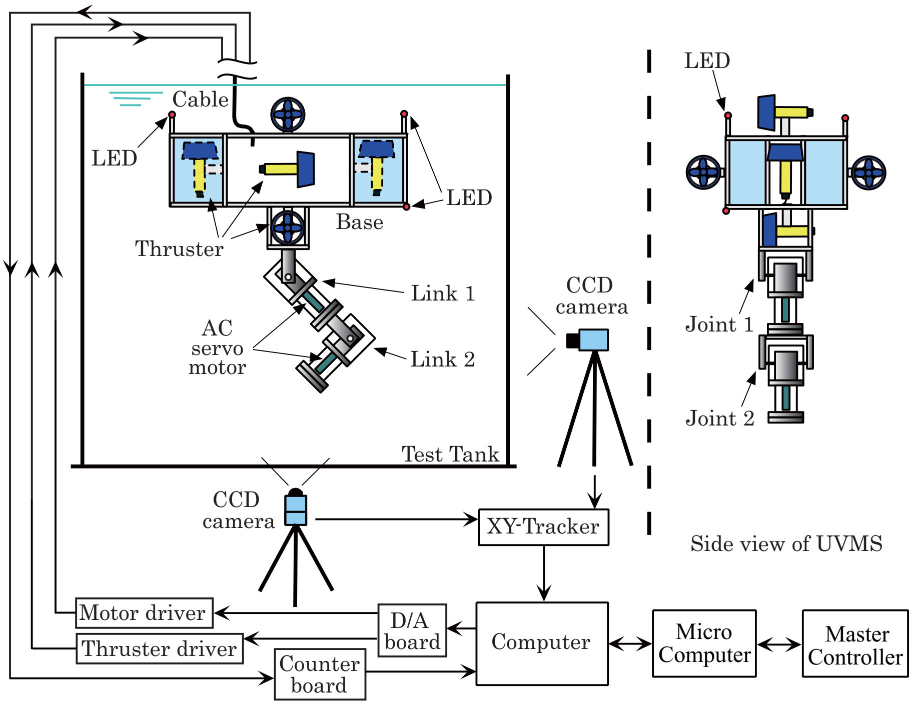

Fig. 5 Configuration of experimental system

3 Experiments

In this section, experiments are done to verify the effectiveness of the master-slave control system for UVMS using the experimental system shown in Fig. 5

Fig. 6 shows an experimental result in the case of the rotational motion. From this figure, we can see that the robot base can follow the posture of the operating device. Especially, it can be seen that the robot base can keep the position and posture in spite of the movement of the manipulator from Fig. 6(b).

Fig. 7 shows an experimental result in the case of the translational motion. The pictures of Fig. 7(a) and (b) were taken from the front of the water tank, and the picture of Fig. 7(c) was taken from the side of the water tank. In this operation, robot base can be operated by using three potentiometers of the base operating device shown in Fig. 8.

4 Conclusion

In this paper, we proposed a master-slave control system for UVMS. Our proposed master controller of the vehicle can manipulate only one hand. The effectiveness of the proposed master-slave control systems was demonstrated by using a floating underwater robot with 2-link manipulator.

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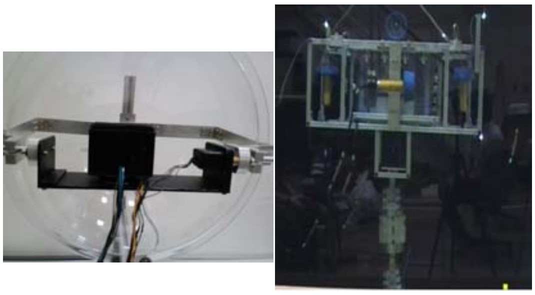
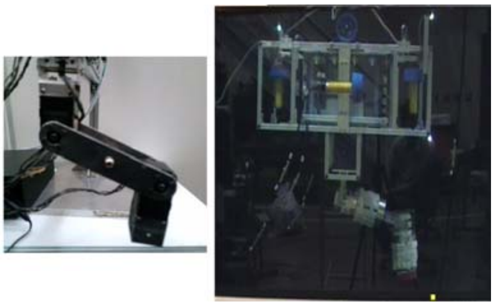
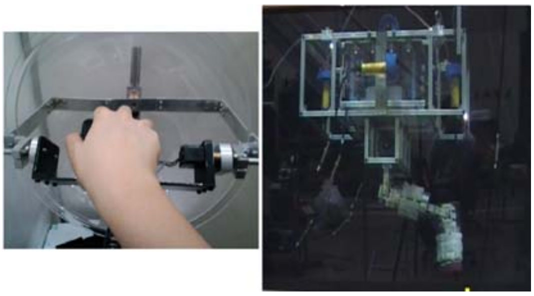


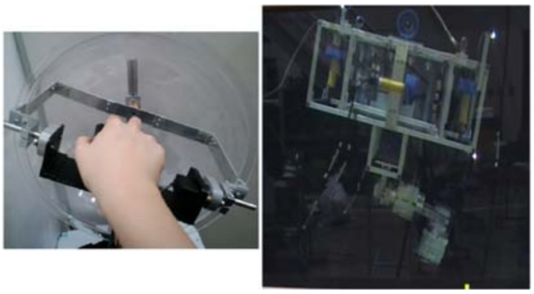
(a) initial posture



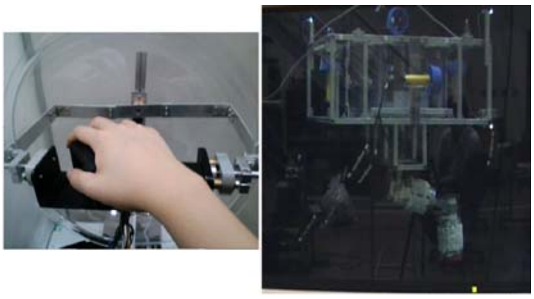
(b) operation of manipulator



(c) operation of base (roll)

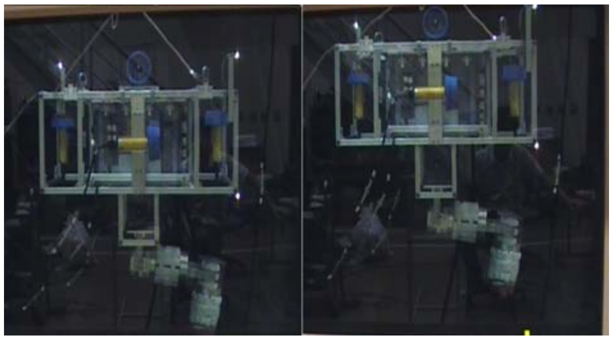


(d) operation of base (pitch)

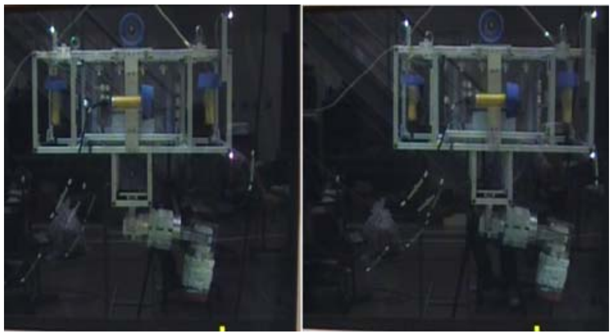


(e) operation of base (yaw)

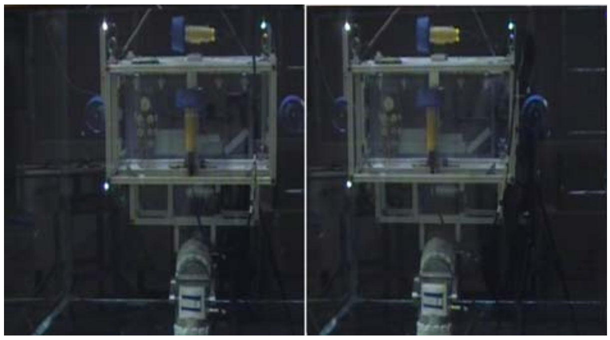
Fig. 6 Rotational motion



(a) vertical direction



(b) horizontal direction



(c) seesaw direction

Fig. 7 Translational motion

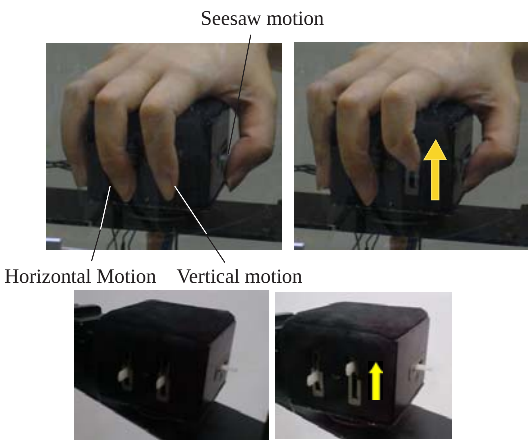


Fig. 8 Operation for translational motion