THE DEVELOPMENT OF REMOTE-CONTROLLED GRAB SYSTEM FOR UNCLEAR ENVIRONMENT

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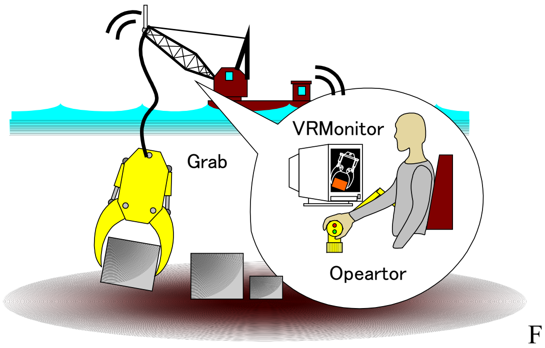
Abstract: Hydraulic Grabs are capable of placing and removing of underwater structures without hitch by divers. However, grab operators are unable to observe states of the grabs and the objects when the turbidness of water disturbs observation by TV cameras. For this reason, operators still need support and observation of divers during positioning of the grab and grasping the object. Therefore, this paper proposes a remotely controlled system that can support operators by representing the motion of the grab and the shape of the objects using sensor data and VR technology. Two types grab models are developed and experiments are carryed out. The experimental result show the validity of the proposed remotely controlled system for unclear environment.

Keywords: Grab, Remote Control, Grasp Works, VR, Underwater Construction.

1. INTRODUCTION

In 1892-1921, Japanese government of Meiji era constructed The Third Fort in Tokyo Bay for the defense of Tokyo, the capital of Japan. However, it was destroyed by the Great Kanto earthquake of 1923, and now is a reef causing the stranding of ships. The Ministry of Land, Infrastructure and Transport of Japan started the removal of the sunken pieces of The Third Fort from 2000 for the safety of the ships cruising in Tokyo bay.

For the removing work, two hydraulic-powered grabs have been developed. The grabs can lift approximate 40-60 ton weighted load up. The grabs have 4 or 8 claws, power units, and are able to rotate around the yaw axis. Especially, the grabs can perform operate without hitching by divers. However, when the seawater is unclear and TV cameras are useless, the grab operator cannot see the grab or the work objects. Hence the operator requires the instruction of the divers in the water. The divers instruct the operator the position of an object and confirm the grasped object whether in balanced condition or not. Therefore, at each period of the instructions, the divers must stand away from the grab. Consequently, the working efficiency of the grab is declined by this refuge time.



F igure 1. Remote-controlled grab system

To cope with this situation, we are developing a new remotely controlled grasping system that enables an operator to perform grasping works without the instruction of divers [1], [2]. In the developed system, the existing state of grasping works can be represented by CG (Computer Graphics) image drawn on the monitor to give visual information in unclear environment. To represent the grasping work by CG image, the following information is required

(a) Objects states: positions and shapes of the objects

(b) Grab state: attitude, position and angles of joints of the grab

(c) Grasping state: confirmation of grasp and detection of object's slip

In the present grab system, the information of (a) is provided by divers and Echo sound profiling system. We have acquired the information of (b) and (c) by using various sensors and estimation methods, and represented the acquired information on a monitor called "The VR Monitor". Figure 1 shows the image of this system.

To verify the effectiveness of this representation method, we develop two types experimental models of the grab.

This paper describes the remotely controlled grab system that enables an operator to do grasping work in unclear environment, e.g., seawater is unclear , by

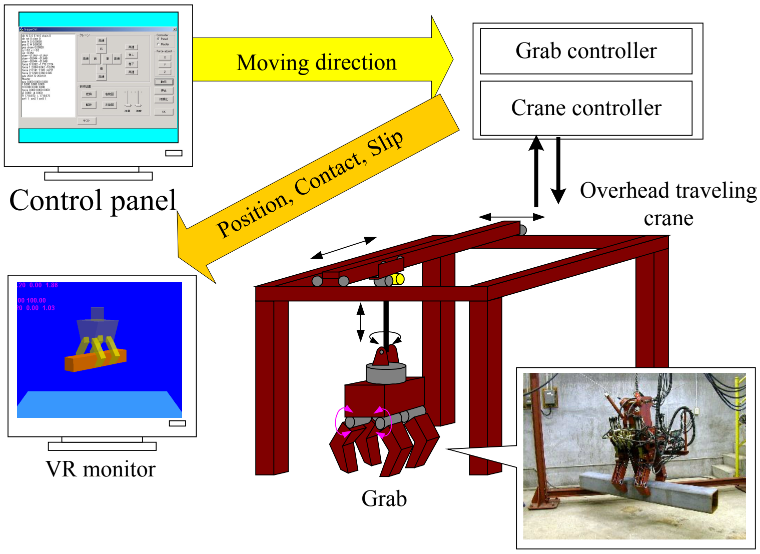


Figure 2. First experimental model

providing visual information based on VR (Virtual Reality) technology and sensors data.

2. THE FIRST EXPERIMENT

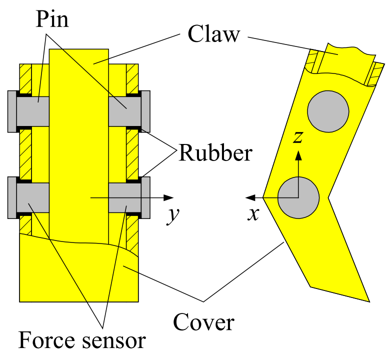
2.1 THE FIRST EXPERIMENT MODEL

The first experimental model of grab shown in Figure 2 is developed to examine basic idea of this remote control system. The developed model has 4 claws and one rotation axis similar to the actual grab. The hydraulic units actuate grab to rotate and grasp an object. This model is able to lift approximate 130kg weighted load up. The grab is capable of 3-dementional positioning by overhead traveling crane. Since the model is suspended by one chain, it is easy to twist and is unstable extremely. To reduce the twisting motion, two tension wires are connected with the garb. Potentiometers measure the angles of joints and rotary-encoders measure the x-y positions of the overhead traveling crane and the fed length of the chain. To obtain more visual information, the grab has contact sensors attached around each claw and slippage sensors mounted on the both sides of the body as shown in Figure 3.

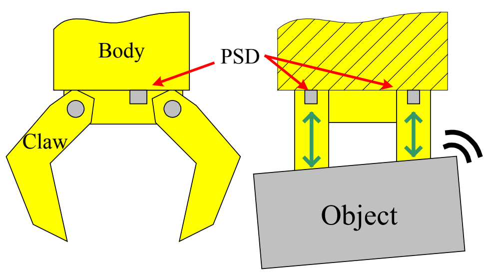
The first grab model has no attitude sensor data, and hence the operator must wait enough time until the swing of the grab stop at its each action.

2.2 GRASPING STATE SENSING

In the filed of robotics, there are many methods have been developed to detect contact and slippage. Most of these methods are for robot hand [3]-[7]. In addition, sensors for such methods are mainly for precision machines, and they are not available under extremely hard conditions such as construction works. Therefore, we have developed new contact sensor and slippage sensor that are able to bear hard conditions.



(a) Contact sensor



(b) Slippage sensor

Figure 3. Sensors to acquiring grasped object state.

(a) CONTACT SENSOR

The contact sensor consists of force sensor units, pin units and claw cover as shown in Figure 3(a). The force sensor units are able to measure the 3-directional forces. The pin units have same frame as the force sensor units. Claw cover is connected with the claw by force sensor units and pin units. When any positions of the claw cover is in contact an object, the contact force acts on force sensor units. By this configuration, the contact sensor is able to detect 3-directional contact and bear the hard condition.

(b) SLIPPAGE SENSOR

Slippage is a change of the distance between the grab and the grasped object. Therefore, the slippage of the object needs to be detected by contact-less distance sensor (Figure 3(b)). PSD (Position Sensitive Detector) sensor is used as a slippage sensor and is attached at the both sides of the grab.

2.3VR Monitor

Grasping work scene is represented on the VR Monitor. The VR Monitor shows the motion of the grab and the shape of targeted objects and ground.

When the grab is in contact with something in the real world, the color of the claw in the CG is changed. In the same way, when the grab grasps and lifts up an object, the CG object is grasped and moved up with the CG grab. When the sensor detects the object slippage, the CG object slips based on the measured distance and then the CG object blinks to inform an operator the slip.

2.4 GRASPING EXPERIMENT

The grasping experiment carried out on ground, in which an operator controls the grab model and removes an object, and places the grasped object on placing site shown in Figure 4. The object is squared steel pipe that weighs approximate 126kg.

This experiment is carried out with three control conditions. The first is direct control by using human eye observation. The second is remote control with VR monitor observation, and the last is remote controlled by using VR monitor observation with initial position error. The position error is enough to cause slippage of the object when the grab grasps and lifts up an object. At each control condition, the operator performs the task five times, and the success rate and work time are evaluated.

From this experiment, it was known that the operator completed the placing operations and accomplished

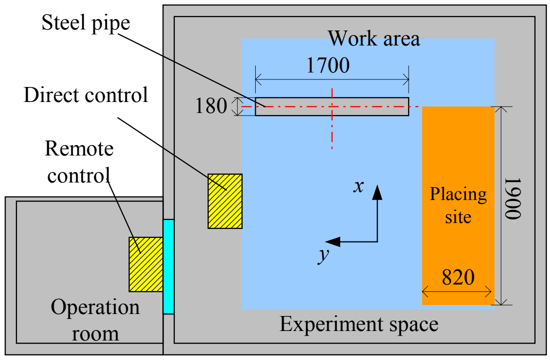


Figure 4. Experimental state.

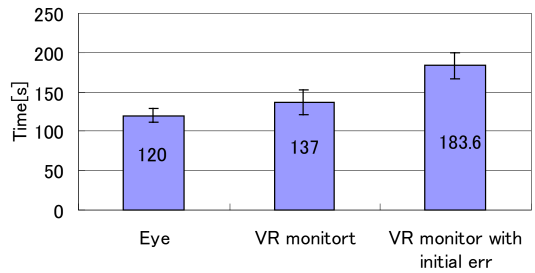


Figure 5. Experimental results of grasping operation

100% success rates irrespective of control conditions. In the case of existing initial position error, the object slipped when the grab lift up the object. In this case, the operator adjusted the grasping position and succeeded the grasping and lifting work again. Experimental results of operation time are shown in Figure 5. The results show that the difference of the operation times between eye and VR monitor observations is very small. It is considered that the grab motion is very slow and furthermore the grab swung at each action, and therefore the operator needs enough time until the grab settle down in any control condition.

Through this experiment, we confirmed that the developed system is effective and useful for the grasping work when seawater is unclear.

3. THE SECOND EXPERIMENT

3.1 THE SECOND EXPERIMENTAL MODEL

Toward to underwater experiment, we have developed the waterproofed type second grab model. This second model has the same mechanical configuration as the first model. This model contains a FOG (Fiber Optical Gyro) attitude sensor that is able to measure the accelerations of 3-axes, angular velocities and inclinations at roll, pitch and yaw axes. Using this sensor, the second system represents the attitude and dynamical motion of the grab. Three force sensors are mounted on the upper body of the grab to measure the weight and the balance of the load. Contact sensors and slippage sensors are still not installed on the second grab. These will be remodeled from the sensors used for the first grab.

3.2 ATTITUDE REPRESENTATION

One way to represent the grab motion is to move the CG grab by the data of the attitude sensor directly. However, the spatial position of the grab is obtained by the integration of acceleration data. So this method has accumulated error problem. As time passed, the represented spatial position of the grab deviates from the actual position more and more. Note that the operator doesn't require high accuracy of representation to control the grab. Important things are the directions and amplitudes of the swing and the twist of the grab.

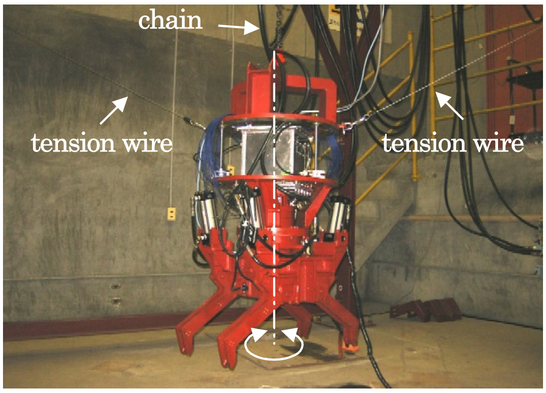


Figure 6. The second model of grab

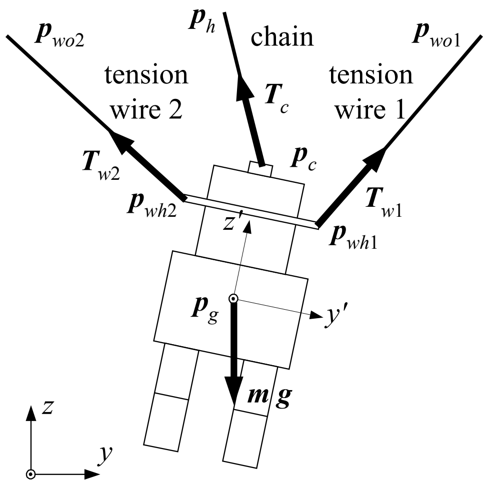


Figure 7. The simulation model of grab

Therefore, the dynamic motion of the grab is represented by the combination of the attitude sensor data and the dynamics model of the grab. The dynamics model is controlled by reference data measured by the attitude sensor. During the grab moves some direction, the dynamics model follows the motion of the grab. And when the grab stops its motion, the state of the grab became stable. In this method, sensor noise, error and drift is reduced or ignored in the motion of the CG grab.

At first sight, the dynamics model is formulated as a simple pendulum, but it is not so simple because the length of the pendulum changes as the fed length of the chain and the base point that is fixed in an ordinary pendulum model is able to move. Furthermore, if the grab touches down the seafloor, the chain is slack, and then the tension of the chain becomes zero. This simulation is not required to represent high precision motion of the grab, and is just required to be processed in real time. Thus, the grab is modeled as one mass system. The constraint by the chain is treated as an external force. The dynamics model of the grab system is shown in Figure 7. The forces exerted on the grab are the tensions of the chain $\boldsymbol{T}_c$, tension wires $\boldsymbol{T}_{w1}$and $\boldsymbol{T}_{w2}$. The dynamical equations of the grab are

$$\left.\begin{aligned} m\ddot{\boldsymbol{p}}_g &= \boldsymbol{T}_c + \boldsymbol{F} + C_v\dot{\boldsymbol{p}}_g + \boldsymbol{F}_c \\ I\ddot{\boldsymbol{\theta}} &= \boldsymbol{\tau} + C_\omega\dot{\boldsymbol{\theta}} + \boldsymbol{\tau}_c \end{aligned}\right\} \qquad (1)$$

where m:mass of the grab, $\boldsymbol{p}_g$:gravity point, $\boldsymbol{F}_c$:control force, C_p:viscosity, I:inertia, $\boldsymbol{\theta}$:inclination, $\boldsymbol{\tau}$:torque, τ_c:control torque, C_w:rotational viscosity. And $\boldsymbol{F}$ is external forces except $\boldsymbol{T}_c$

$$\boldsymbol{F} = m\boldsymbol{g} + \boldsymbol{T}_{w1} + \boldsymbol{T}_{w2} \qquad (2)$$

$\boldsymbol{T}_c$ acts when a distance $\boldsymbol{d}$ from the chain fed point of a hoist $\boldsymbol{p}_h$ to the chain joined point at the grab $\boldsymbol{p}_c$ is equal to or exceeded real length of the chain L_c. $\boldsymbol{T}_c$ is computed as follows:

$$\left.\begin{aligned} T_c &= -\frac{\boldsymbol{d}}{|\boldsymbol{d}|}(|\boldsymbol{F}| + k_c(L_c - |\boldsymbol{d}|) - C_c\dot{\boldsymbol{d}}_c) : \boldsymbol{L}_c \le |\boldsymbol{d}| \\ T_c &= 0 \qquad\qquad\qquad\qquad\qquad : otherwise \\ \boldsymbol{d} &= \boldsymbol{p}_c - \boldsymbol{p}_h \end{aligned}\right\} \qquad (3)$$

where k_c is spring constant. C_c is viscosity that stabilizes tension wire system.

The tension wire i force T_{wi} increases according to the wire fed length L_{wi} and is given by

$$\boldsymbol{T}_{wi} = -k_{wi}\boldsymbol{L}_{wi} - T_{wo}\frac{\boldsymbol{L}_{wi}}{|\boldsymbol{L}_{wi}|} - C_w\dot{\boldsymbol{L}}_{wi} \qquad (4)$$

$$\boldsymbol{L}_{wi} = \boldsymbol{p}_{wsi} - \boldsymbol{p}_{woi}$$

where k_{wi}: spring constant, p_{whi}:wire hooked point at the grab, p_{woi} :origin position of wire, C_w: feeding viscosity. C_w is required to regulate the motion of the grab.

Exerted torque τ is

$$\boldsymbol{\tau} = \boldsymbol{T}_c \times (\boldsymbol{p}_c - \boldsymbol{p}_g) + \boldsymbol{T}_{w1} \times (\boldsymbol{p}_{wh1} - \boldsymbol{p}_g) + \boldsymbol{T}_{w2} \times (\boldsymbol{p}_{wh2} - \boldsymbol{p}_g) \quad (5)$$

The motion of the dynamics model is modified by the actual attitude sensor data. The controller of dynamics model is PD controller. Translation control force $\boldsymbol{F}_c$ revises error between real acceleration $\boldsymbol{a}_r$ and simulated acceleration

$$\boldsymbol{F}_c = k_{ap}(a_r - \ddot{\boldsymbol{p}}_g) + k_{ad}(\dot{a}_r - \dddot{\boldsymbol{p}}_g) \quad (6)$$

where k_{tp} and k_{td} are control gains of for the translation control.

The rotation control force τ_c compensate inclination between the real and the virtual coordinate axis of the grab

$$\begin{aligned} \boldsymbol{\tau}_c &= k_{rp}\boldsymbol{t} + k_{rd}\dot{\boldsymbol{t}} \\ t &= \boldsymbol{i}_r \times \boldsymbol{i}_s + \boldsymbol{j}_r \times \boldsymbol{j}_s \end{aligned} \quad (7)$$

where $\boldsymbol{i}_r$ and $\boldsymbol{j}_r$: x and y coordinate axes of the real grab, $\boldsymbol{i}_v$ and $\boldsymbol{j}_v$: x' and y' coordinate axes of the virtual grab, $k_{rp}$and k_{rd}: control gains

The CG grab is drawn on the VR Monitor by the motion of the simulation model. This simulation is calculated by the 4th order Runge-Kutta method at period of 10ms.

3.3 EXPERIMENT OF ATTITUDE REPRESENTATION

To confirm the validity of this representation method, experiment is performed using the second model of grab. The grab moves by time sequenced commands and the data of the attitude sensor are recorded. The time sequenced commands are shown in Table 1. The simulated positions and inclinations are compared with the reference data to confirm the validity of the representation method. The measured position is the point $\boldsymbol{p}_c$ in Figure 7. The reference position of the grab is measured by positioning device consisting of three wire encoders attached at the three corners of the overhead traveling crane frame. The spatial accuracy of the positioning device is approximate ±1cm.

The experimental results of positions and inclinations are shown in Figure 9. The results of x, y position data show that the simulated data are corresponding to the reference data well. In the result of z position,

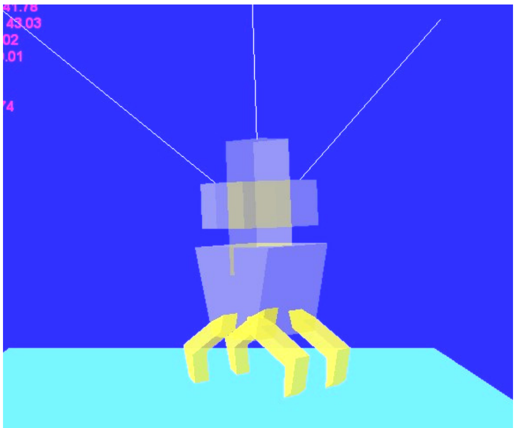


Figure8. Represented CG image of the swinging grab

Table 1. Sequential motion command

Time[sec]	x	y
0	forward	stop
1	stop	forward
2	backward	stop
3	stop	backward
4	stop	stop

the change of simulated the z position is small. This is the reason why the chain of simulated model has spring characteristic shown in equation (3). However, in this simulation, the accuracy of the z direction is enough to observe the motion of the grab. In the results for roll, pitch and yaw inclination angles, the simulated data are corresponding to the reference data well.

As a result, it is clarified that the proposed representation method in this paper is effective to observe the dynamic motion of the grab.

4. CONCLUSION

This remotely controlled grasping systems have the possibility of grasping operation in unclear environment. For practical use of this system, it requires the following subjects:

(1) Waterproofed contact sensor.

(2) Slippage sensor using multiple ultrasonic distance sensors.

(3) Attitude estimation when the grab touch down on seafloor.

As a next step of this study, we have a plan to perform test tank experiment in waves and water current and apply this system to practical grab. By introducing of this remotely controlled grab system, the safety and the efficiency of underwater construction will be increased.

Acknowledgments

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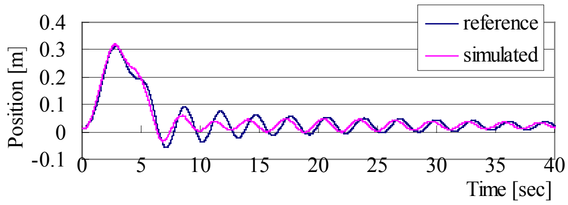
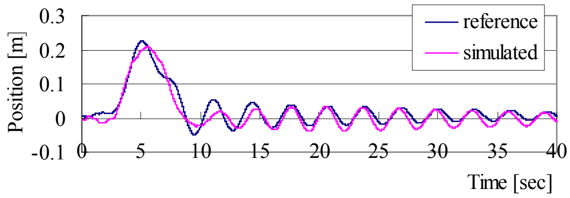
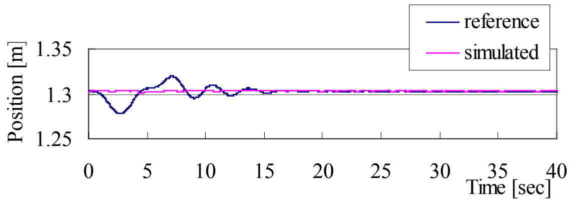


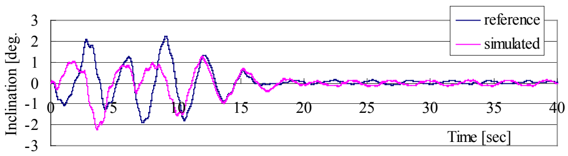
(a) *x* axis



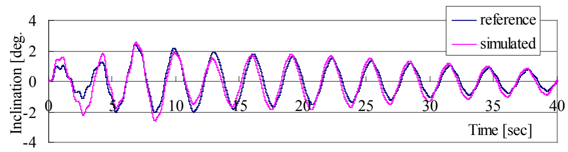
(b) *y* axis



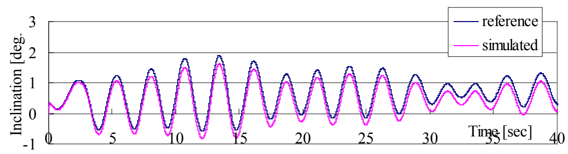
(c) *z* axis



(d) roll



(e) pitch



(f) yaw

Figure 9. Experimental result of the grab attitude