The crucial information for improving manipulator operation
— No. 1 : In case of crane operation —

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ABSTRACT

Skilled rough terrain crane operators say that they take many sensory information for getting more precise movements of a machine. The first experiment in this paper reveals which sense is the most important factor for crane operation. By using a 25ton crane simulator, (visual, acoustical and tactile) information of an actuator speed was given to operators so as to assist their operation of stopping the load oscillation. The best result, both the task performance and the sensory evaluation of the operating feeling, is got by using the visual information feedback method. Then a new multi-display system is proposed that enables a crane operator to lessen the load oscillating amplitude very easily by adjusting the actuator operation lever position to the oscillating load position. (Patent pending) The second experiment demonstrate the effectiveness of this new multi-display system.

1. INTRODUCTION

The most important points to evaluate the easiness of operation of a crane are to be said as follows;

- hardness to oscillate the load
- easiness to lessen the oscillation

Previous study[1] point out that a crane with a longer time constant of an actuator tend to lessen the amplitude of the oscillation. It is also revealed that making hard to cause oscillation of a load is basically achieved by taking more care about manipulating an actuator at the start point of a load movement. On the other hand, the second point is mainly effective near the destination of a load movement, because the operation that lessen the load oscillation is mostly done at that time in real crane work.

There are a lot of researches on stopping its oscillation by controlling an actuator's movement automatically, and some of them are already introduced into many actual working cranes, such as tower cranes at construction site, that usage are limited to sub-routine work. Considering rough terrain crane operation, most of them are non-routine work. So it is very difficult to controlling an actuator's movement automatically and it is said that a rough terrain crane should be operated manually for quite a long years[2].

It is supposed that the more (suitable) information about movements of a machine a crane operator has, the more improved operation they can display. It was therefore considered worthwhile to carry out an experiment that can make clear what information is crucial for improving crane operation. (Experiment 1)

Based on the results of Experiment 1, we invent a new multi-display system[3],[4] (Patent pending) that makes a crane operator lessen the load oscillating amplitude easily. In order to demonstrate the effectiveness of this new multi-display system, another experiment is carried out.

2. EXPERIMENT 1

2-1. A SURVEY OF THE CRANE SIMULATOR

The crane simulator is modeled on actual 25ton rough terrain crane and has its first order system character. The actuator speed is in direct proportion to the control lever angle. As shown in Fig.1, the analog voltage signal of the control lever angle is taken to a personal computer through the A/D converter and the digital data is send to a workstation. Then the crane boom and the load positions are calculated by the workstation, displayed on a 21 inch monitor.

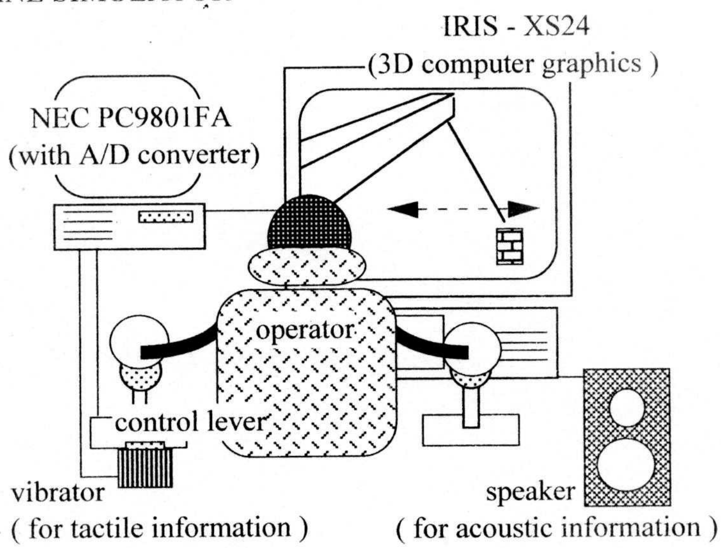

Fig.1 Crane Simulator

2-2. EXPERIMENTAL PROCEDURES

The first experiment was carried out with three volunteer subjects. Subjects were required stopping the oscillation of the load (the initial oscillating amplitude was 30cm) by operating the swing control lever, the number of operations for stopping the oscillation was counted. The load oscillating period was 9 seconds, that is correspond to 20m wire cable length. Four ways of information feedback methods (including No feedback) mentioned below were tested by all subjects. They were required to stop the oscillation for 5 to 7 times in each information feedback session, in order to get rather stable data. The feedback information was the speed of the top point of the boom. The sensory evaluation of the operating feeling was answered by using the pilot opinion rating method.

(1) No feedback : No information feedback (conventional crane)

(2) Visual feedback : Light up and down above the hook according to the speed of the boom (Fig.2-1)

(3) Acoustic feedback : Beep frequency up and down according to the speed of the boom (Fig.2-2)

(4) Tactile feedback : Vibration frequency up and down according to the speed of the boom (Fig.2-3)

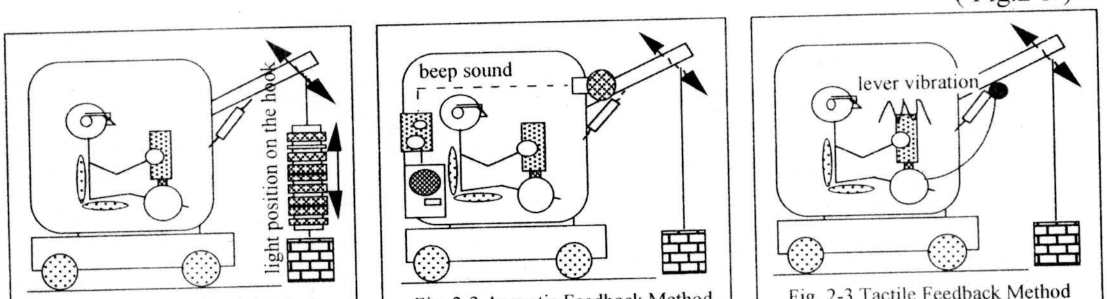

Fig. 2-1 Visual Feedback Method

Fig. 2-2 Acoustic Feedback Method

Fig. 2-3 Tactile Feedback Method

Fig.2 Feedback Methods of The Boom Velocity

2-3. SUBJECTS

All the subjects joined this experiment have "Mobile Crane Operating Licence (inclusive of rough terrain crane)" and know the basic crane operation well.

3. RESULTS OF EXPERIMENT 1

The count of lever operation data handled as follows;

(1) Calculate average count of the lever operations of the No feedback session for individual subject.

(2) Normalize each subject's data by the individual 'basic average data' that calculated above.

Fig.3 and 4 show that the Visual feedback method is the only one which has better results both in the performance and the sensory evaluation.

Therefore it is supposed that setting a visual feedback system on actual crane is very helpful for operators. But putting any display device near the hook is very difficult to realize. So we discussed to make out more realistic display device and a new multi-display system is invented.

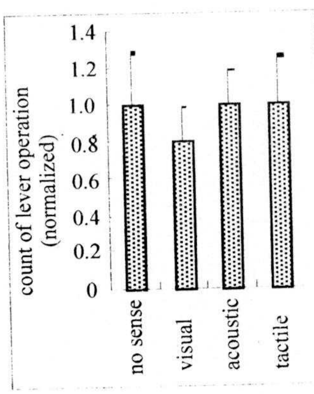

Fig.3 Average Count of Lever Operation

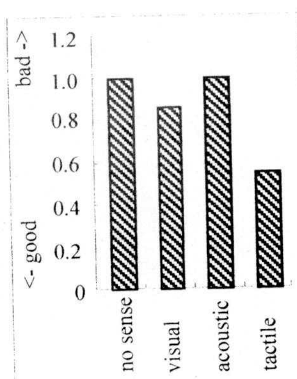

Fig.4 Average Sensory Evaluation Score

4. NEW MULTI-DISPLAY SYSTEM (PATENT PENDING)

Fig.5 shows a survey of the new-invented multi-display system. Considering rough terrain crane work, usually a load is suspended from the top of the boom through a long wire. Basic operation for stopping the oscillation is to set the boom top position just above the load position. In case of actual operation, it is quite difficult to operate the control lever appropriately, mainly because that one can not easily get the boom top speed information. Especially in case of a load oscillation along the boom hoist direction, to reduce its oscillation becomes more difficult. The reason is that it is very difficult to know the load movement because the direction of the load oscillation is nearly the same one of the operator's glance and usually the load is far from the operator's seat, its oscillation hard to distinguish. In order to control the lever more easily, the new multi-display system were invented.

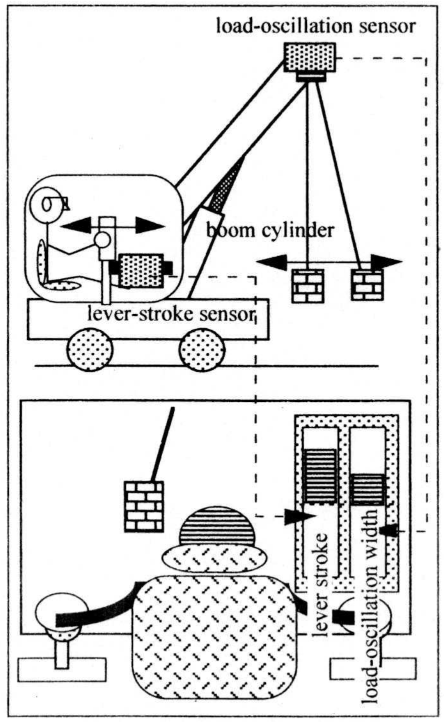

Fig.5 New Multi-Display System to Assist Oscillation Control

Using the new multi-display system, it is very easy for stopping oscillation of a load. The required operation for an operator is to set the mark of the lever position gauge to the mark of the load oscillation position gauge by controlling the lever.

5. EXPLANATION FOR NEW MULTI-DISPLAY SYSTEM

Following is the brief explanation how to work the new Multi-Display system for stopping a load oscillation. (see Fig.6)

The equation of motion of the load is

$$m\ddot{x}_2 = -T\sin\beta \qquad (1)$$

$$m\ddot{y}_2 = T\cos\beta - mg \qquad (2)$$

where

x_1, y_1 : Location of the Boom Top

x_1, y_1 : Location of the Load

L : Length of the wire cable

m : Mass of the Load

T : Tension of the wire cable

β : Angle of oscillation

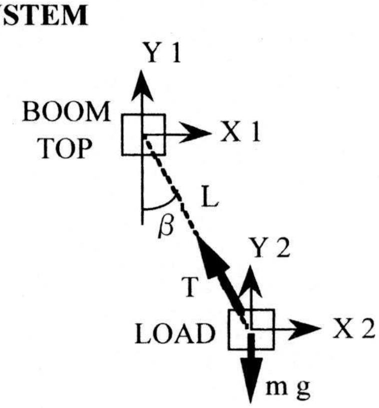

Fig.6 Pendulum Model

if $\beta \approx 0$ then $\ddot{y}_2 = 0, \cos\beta = 1, \sin\beta = \beta$
from Eq.(2) we have

$$T = mg$$

applying this to Eq.(1), we get

$$\ddot{x}_2 = -g\beta \qquad (3)$$

let the load

$$x_d = x_2 - x_1 = L\sin\beta = L\beta$$

thus

$$\beta = \frac{x_d}{L} \qquad (4)$$

applying this to Eq.(3), we obtain

$$\ddot{x}_2 = -\frac{g}{L}x_d, \quad (\ddot{x}_d + \ddot{x}_1) = -\frac{g}{L}x_d,$$

$$\ddot{x}_d + \frac{g}{L}x_d + \ddot{x}_1 = 0 \qquad (5)$$

now, if the boom top moved as $\dot{x}_1 = \alpha x_d$ (α : damping coefficient)

$$\ddot{x}_d + \alpha\dot{x}_d + \frac{g}{L}x_d = 0 \qquad (6)$$

From this Eq. we can see boom speed comes to the damping term of the load oscillation width x_d.

In case of crane operation, speed proportional control lever is used, so let the displacement of the lever x_3 (γ : proportional coefficient)

$$x_3 = \gamma\dot{x}_1 = \gamma\alpha x_d \qquad (7)$$

It is obvious from Eq.(6) and (7) that one can reduce the amplitude of the load oscillation by setting the lever displacement to the load oscillation width.

6. EXPERIMENT 2

6-1. EXPERIMENTAL PROCEDURES

The second experiment was carried out, with three volunteer subjects. Subjects were required stopping the oscillation of the load by operating the hoist control lever. The initial oscillating amplitude angle was 0.1 rad and the operating time was measured until the oscillating amplitude angle was reduced to 0.01 rad. Two sessions were done, the one was no display system (conventional crane) and the other was with Multi-Display System. The crane model and the load condition are the same as Experiment 1.

6-2. SUBJECTS

All the subjects joined this experiment were the university students.

7. RESULTS OF EXPERIMENT 2

Fig.7 shows there are more than 30% reduction in operating time of all the subjects. The effectiveness of the Multi-Display System are clearly confirmed by this experiment.

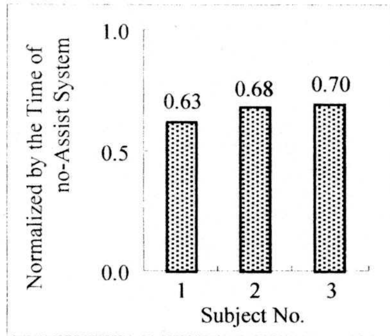

FIg.7 Required Time of Stopping the oscillation of the Load (with the Multi-Display system)

8. CONCLUSIONS

For the rough terrain crane operation, it is considered that which sense (visual, acoustical and tactile) is the most important sense to feedback for improving the operation in stopping the load oscillation. The visual feedback method shows better results both in the performance and the sensory evaluation.

Based on the results mentioned above, we proposed a new Multi-Display system that make ease of stopping the oscillation by controlling the mark of the lever position gauge to the mark of the load oscillation position gauge. The effectiveness was confirmed by using both the theory and the experiment.

9. ACKNOWLEDGMENTS

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