MANUAL CONTROL OF A FLEXIBLE ARM AND APPLICATION TO AUTOMATIC CONTROL SYSTEMS

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Abstract: A human operator has the ability to control a complicated system such as a gantry crane, an aircraft and a remote manipulator after enough training and learning. In this article, we attempt the positioning experiment of a flexible arm by a human operator. Flexible arm has nonlinearlity and infinite-degrees of freedom in general; thus it is difficult to obtain a control input. The operator interprets a given task and finds the procedure of operations. He devises an effective way of achieving the goal on the basis of his experience and knowledge about the task.

1. Introduction

Transverse vibration occurs when a light weight arm moves, especially carries a heavy payload mass. In such cases, the arm cannot be regarded as a rigid body. Elasticity of the arm should be taken into consideration. This kind of positioning control is of technological interest, and several papers on it have been published during past years. Cannon and Schmitz[1] controlled a flexible arm by using an optical sensor to detect tip position. Sakawa, Matsuno and Fukushima[2], Fukuda[3] and Truckenbrodt[4] used a strain gage attached to the flexible arm as a sensor for the vibration. Harashima, Ueshiba and Hashimoto[5] used a CCD camera to measure a tip position. Hanafusa, Nakamura and Kadokawa[6] applied a accelerometer to control a tip position. A human operator can control the complicated systems such as a gantry crane, an aircraft and a remote manipulator, etc. after enough training without any special devices[7-8]. Thus, in this article, we attempt the positioning experiment of a flexible arm by a human operator. Using these experimental results, we propose the procedure of designing a reference input filter.

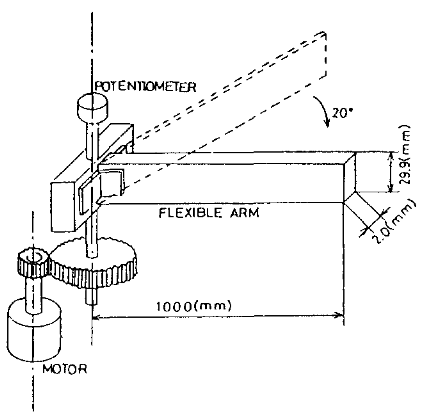


Fig.1 Experimental Arm.

2. The experimental device and experimental process

Figure 1 shows the experimental arm. It is a 1000mm long, 29.9mm thick, 2.0mm width, very flexible structure that can bend freely in the horizontal plane but not in the vertical plane or torsion. At one end, the arm is clamped on a rigid hub mounted on the vertical gear shaft(gear ratio N=5) which is driven by a dc motor; a torque applied by the motor rotates the arm in the horizontal plane. The manual control has two types. One is a open loop type and second is a closed loop type. In the first type, the operator's problem is to generate the input torque directly. On the other hand, in the second type, the operator's problem is to make the output of the controlled process correspond as closely as possible to the reference input. The closed loop type manual control is more easy to control than the open loop type one. Thus we used the closed loop type manual control. The dc motor(SANYO DENKI SM60) is driven by a current amplifier and is provided with a potentiometer(MIDORI PRECISIONS CP-2U). The controller is used single-turn wire wound potentiometer(MIDORI PRECISIONS CP-4M). The controller is a position transducer at joint that measures the motion of the human operator as he moves it. Thus the operator's motion is transformed into electrical signals which are transmitted to the mechanical arm and cause the same motion as the one that the human operator performed. The angular signal from the potentiometer is amplified and filtered by an analog low-pass filter. This filter's cut-off frequency is 100Hz. The signal is then digitized by an analog-digital(A/D) converter. And this signal is sent to a computer; these data are stored in its memory. The measurement of motions of the arm is used CCD video camera(SONY XC-37). A human operator watches a monitor T.V. and moves the potentiometer. Figure 2 is a block diagram in the case of a manual control experiment. In this case the sampling period used for the computer input is 10.6[ms] and it used for measurement of tip position is 1/30[sec].

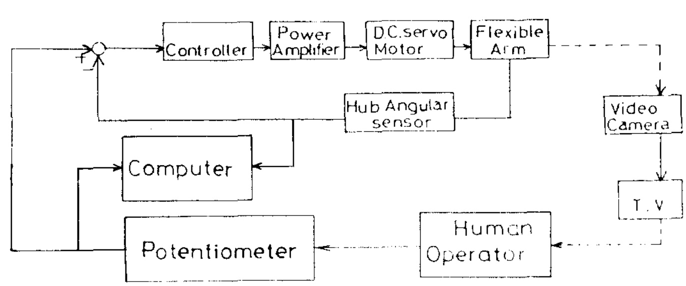


Fig.2 Block Diagram(Manual Control).

3. Experimental results

The step function is added as a reference input, instead of a human operator, in Figure 2. The loop gain K is chosen as K=0.0865[kgm/V]. Figure 3 show the results. In the Figure, the solid line shows the tip position response and the dashed line is the result for the hub angle response. The tip moves initially in the negative direction. Thereafter, the tip moves rapidly to the commanded direction with large overshoot and damps very slowly.

Figure 4 is an example of the manual control. This result is far from a desired movement. Figure 4(a) is the tip position response and the hub angle response and Figure 4(b) is the reference input. As compared with Figure 3, overshoot is smaller but residual vibration is exciting rather than slow to damp. This reference input has a contrary effect. Figures 5-7 show the successful examples. In the Figures the human operator shows three representative

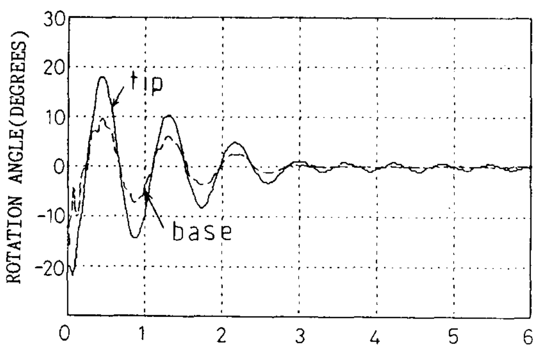


Fig.3 Unit Step Response.

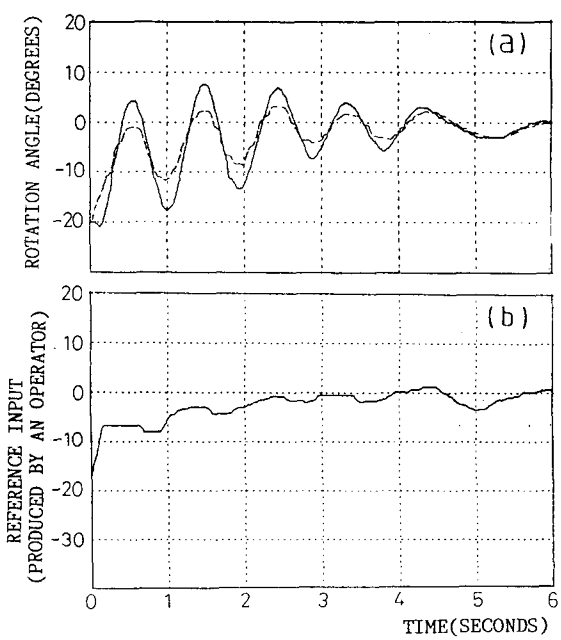


Fig.4 Manual Control Example I.

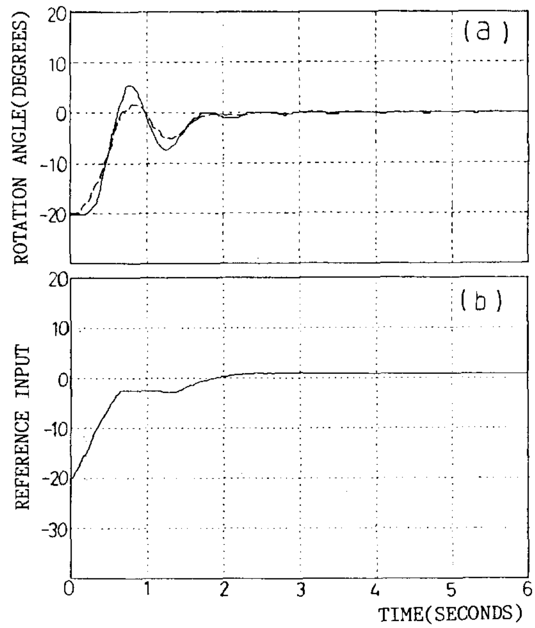


Fig.5 Manual Control Example II.

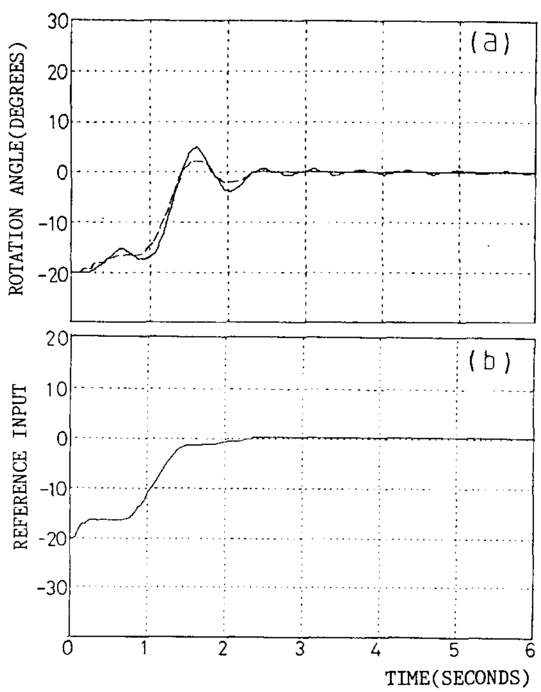


Fig.6 Manual Control Example III.

operational patterns. First, in the beginning time he quickly moves near the commanded position and after slowly moves to the commanded position(Figure 5). Second, in the first time he start slowly to move and after rapidly moves the commanded position(Figure 6). Third, he smoothly moves from beginning to end(Figure 7). Those characteristics are that operator inputs an effective torque first 2 seconds and operates nothing after that. This is the reason why human operator is unable to control a minute vibration. Thus the human operator utilizes a system damping characteristic. If he controls a minute vibration, he will excite the vibration as shown in Figure 4(a).

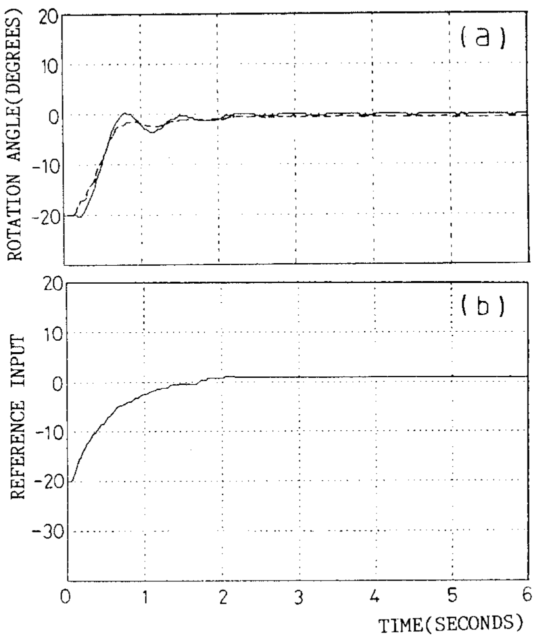
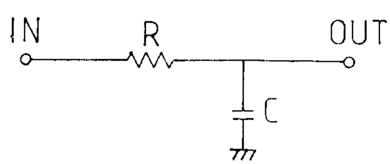


Fig.7 Manual Control Example IV.

4. Reference input filter

The results of manual control experiments will be applicable to automatic control systems in several ways. A direct application is the use of the signal produced by an operator; the computer reproduces the stored signal in real time which can be a reference input to the system. This method necessitates the use of a computer. The use of the filter is another simpler way which produces a reference input from a step function as shown in Fig. 8(a). Let us consider the case of Figure 7; this seems the most effective reference input. Considering the

(a) Block Diagram



(b) Filter Circuit

Fig.8 Reference Input Filter.

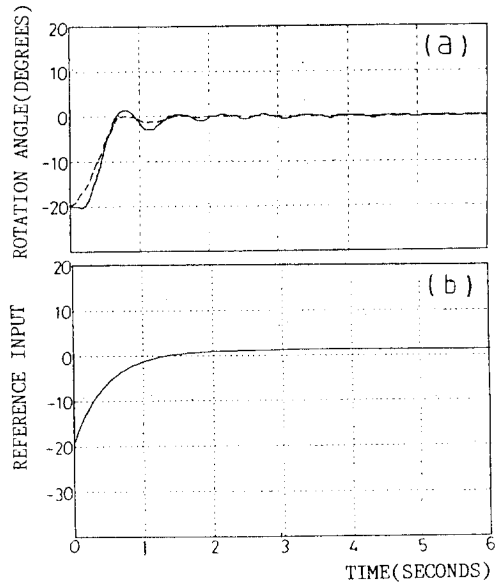


Fig.9 Reference Input Filter Experiment. (T=0.536)

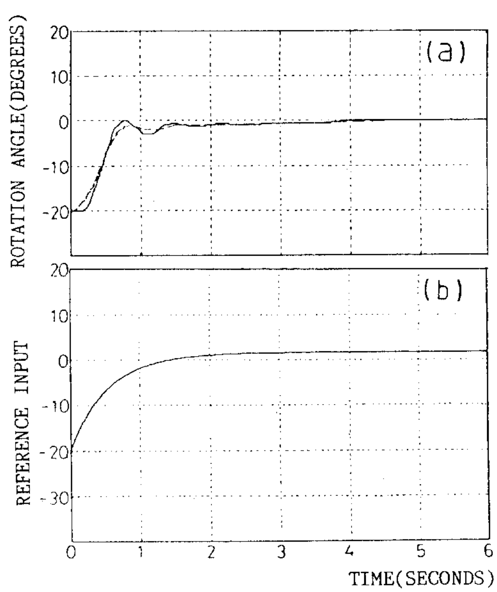


Fig.10 Reference Input Filter Experiment. (T=0.641)

shape of the time function, we use the first-order lag circuit of Fig. 8(b) as a filter. The input-output relation G(s) of the filter is given by

$$G(s)=\frac{1}{1+Ts},$$

$$T=CR.$$

The experimental results are in Figures 9-11. If the time constant is larger, the overshoot does not exist, the residual vibration is rapidly damped but settling time is longer. If the time constant is smaller, the overshoot is larger, the residual vibration is slow to damp and the settling time is shorter. Figure 10 is the best result in this experiments. As compared with Figure 7(a), it is very similar to Figure 7(a), but it has a little overshoot.

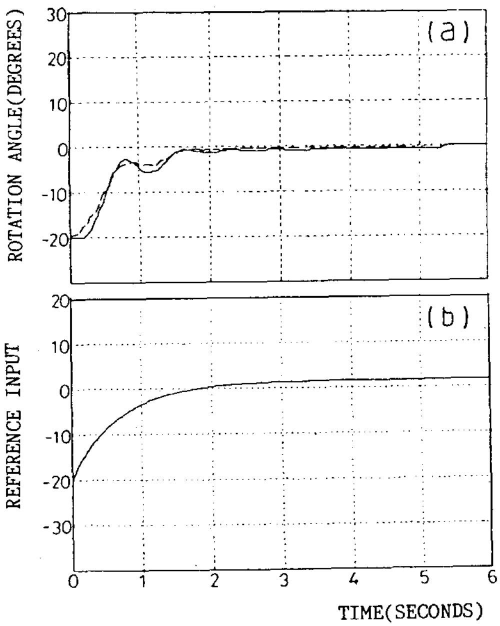


Fig.11 Reference Input Filter Experiment. (T=0.781)

5. Concluding remarks

In this article, we attempt the positioning experiment of a flexible arm by a human operator. The operator interprets a given task and finds the procedure of operations. He devises an effective way of achieving the goal on the basis of his experience and knowledge about the task.

These results may bring about the following questions.

1. To what extent can a human operator control a flexible arm ?
2. What is the movement of a hub which does not cause the minute vibration of the arm ?
3. How are these results applied to automatic control systems ?

In this article we consider the third question and propose the use of a reference input filter. The filter gives a satisfactory overall response if the time constant is chosen appropriately. The reference input corresponds to the rotation angle of 20 degrees. If the angle differs, the time constant will change in general. However, if the angle is smaller than 20 degrees, the same time constant shows good results.

Such ability of a human operator to find a control pattern will be applicable to many fields, especially to teaching playback control systems.

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