Consideration of Human Operators in Man-Machine Systems

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Abstract: This paper focuses on the stability and operability of a man-machine system considering a human operator. Some papers' main interest has been the stability only, but the operability such as fatigue is also the other main interest. In a man-machine system, feelings such as motional, visual, and kinesthetic are important since those enable operators to work easily or fatigue operators. A model of a man-machine system has been developed. Motional, visual, and kinesthetic feelings may be considered as feedbacked sensor signals. We also have quantified the degree of fatigue with respect to reference operation. This is a performance index to be optimized. Several methods are presented to optimize the degree of fatigue and the stability of the integrated system. Examples are presented to show that the usefulness of the proposed modeling method and fatigue mitigating algorithm.

Keywords: Man-machine system, human operator, stability and operability, servo manipulator, teleoperation.

1. INTRODUCTION

A man-machine system is a system in which the functions of a human operator and a machine are integrated. It is a very widely applicable but ambiguous definition. So we limit the scope of a machine to control systems such as servo manipulators, teleoperations, automobiles, and aircrafts.[1-4] Since a human operator and a control system(or machine) are incorporated, the system has to be considered not only separately but also totally. [5-10] In this paper, the stability and operability of a man-machine system are focused on. Some papers' main interest has been the stability only, but the operability such as fatigue is also the other main interest. In a man-machine system, feelings such as motional, visual, and kinesthetic are important since those enable operators to work easily or fatigue operators.

A model of a man-machine system has been developed. Motional, visual, and kinesthetic feelings may be considered as feedback sensor signals. We also have quantified the degree of fatigue with respect to reference operation. This is a performance index to be optimized. Several methods are presented to optimize the degree of fatigue and the stability of the integrated system. Numerical examples are presented to show that the usefulness of the proposed modeling method and fatigue mitigating algorithm.

2. HUMAN OPERATORS IN MAN-MACHINE SYSTEMS

Generally, a man-machine system is composed of three components: a human operator, a machine, and environment. Typical examples of man-machine systems are servo manipulators, automobiles, and aircrafts. These interact with operators and environment continuously. Table 1 shows examples of man-machine systems.

Table 1. Typical examples of man-machine systems

Man	Machine	Environment
Trained operator	Servo manipulator	Equipment, Workpieces
Trained surgeon	Surgical manipulating instrument	Tissues
Driver	Automobile	Roads
Trained pilot	Aircraft	Atmosphere

Rigorously, environment is not a component, but it is included in this paper. Roads are not affected by a machine, but workpieces or tissues are done. Figure 1 shows the conceptual diagram of components' interrelation.

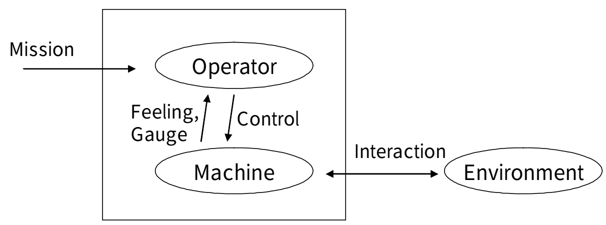


Fig. 1 The conceptual diagram of interrelation.

The block diagram of a man-machine system can be represented as Figure 2 from the viewpoint of control engineering.

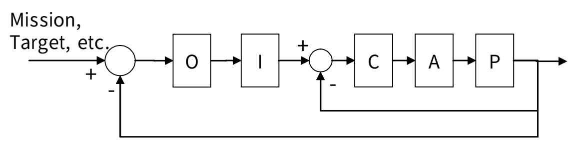


Fig.2 Control block diagram of a man-machine system. (O: operator, I: input device, C: controller, A: actuator, P: plant)

The system consists of two loops: the inner one is for servo actuation, and the outer one is for operator's control. C controls the inner loop, but O controls the outer loop or the total system.

A distinguished trend of a man-machine system is that a direct actuation is being replaced by a servo actuation. It is well illustrated by Figure 3. In case of the servo actuation, a machine is driven by a servo actuator that is electrically linked to a servo actuator driving an input device. Input devices may be a steering wheel, a control stick, a haptic device, and a master manipulator. A servo actuator for an input device is necessary to give feelings of interaction. If these feelings are not available, proper controls are not possible.

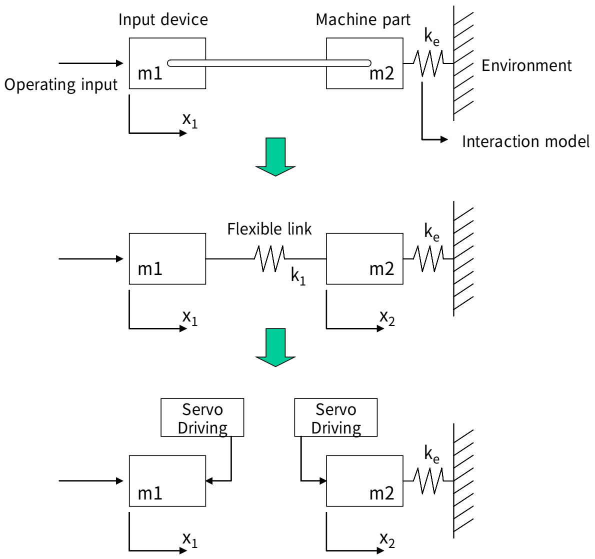


Fig. 3 Trend of a man-machine system's actuation.

The servo actuation has many advantages. It has realized several augmented systems(for example autopilots), and teleoperation. However, it has induced a stability problem. Disturbances, delays, or in a communication channel may induce unfavorable phenomena.

Dynamic models for Figure 3 are presented. The spring type model for the interaction with environment is general.

$$\frac{f_s}{u} = \frac{k_e}{(m_1+m_2)s^2 + cs + k_e} \tag{1.a}$$

$$\frac{f_s}{u} = \frac{k_e k_1}{(m_1 s^2 + c_1 s + k_1)(m_2 s^2 + c_2 s + (k_1 + k_e)) - k_1^2} \tag{1.b}$$

The third one requires more. The position of the input device is the command of the machine, and the interactive force with environment is the force reflection to the input device.

$$\begin{aligned} m_1\ddot{x}_1 + c_1\dot{x}_1 + k_1 x_1 &= u - u_{s1} \\ m_2\ddot{x}_2 + c_2\dot{x}_2 + k_e x_2 &= u_{s2} \end{aligned} \tag{2}$$

where $u_{s1} = k_{FR} f_s = k_{FR} k_e x_2$ and $u_{s2} = k_c x_1$. Then,

$$\begin{bmatrix} m_1 s^2 + c_1 s + k_1 & k_{FR} k_e \\ -k_c & m_2 s^2 + c_2 s + k_e \end{bmatrix} \begin{bmatrix} x_1(s) \\ x_2(s) \end{bmatrix} = \begin{bmatrix} u(s) \\ 0 \end{bmatrix} \tag{3}$$

and finally

$$\frac{f_s}{u} = \frac{k_e x}{u} = \frac{k_e k_c}{(m_1 s^2 + c_1 s + k_1)(m_2 s^2 + c_2 s + k_e) + k_c k_{FR} k_e} \tag{4}$$

A human operator has been modeled a controller. Doman and Anderson[9] proposed a fixed order optimal control model. Julian[8] presented human responses for feelings such as vision, tactile. Lee[5] and Penin[6] presented dynamic models for human behavior in a master-slave teleoperation. In the paper, we model human behavior as a simple PID controller since it is easy to analyze and its behavior is similar to human. But parameters of the controller depend on operators.

3. STBILITY AND OPERBILITY OF MAN-MACHINE SYSTEMS

Consider the first one of Figure 3. The operator is modeled as a P controller.

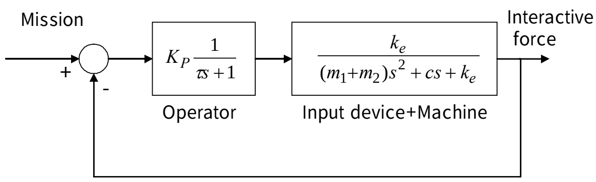


Fig. 4 Control model of a man-machine system.

The term $1/(\tau s+1)$ means an operator's response property. Sensitive or trained operators may response quickly, so τ may be small, and *vice versa*. The original system is stable if environment is not too much stiff. The root locus for the system is the following.

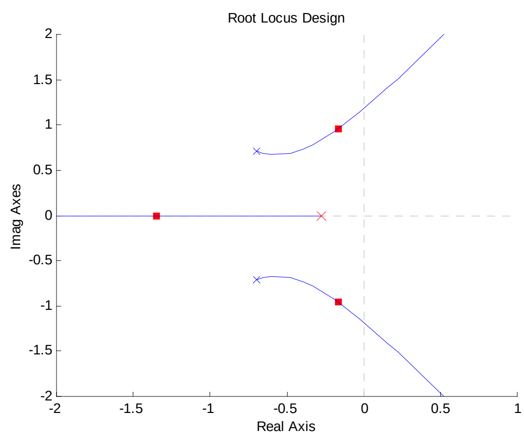


Fig. 5 Root locus of the control system of Figure 4.

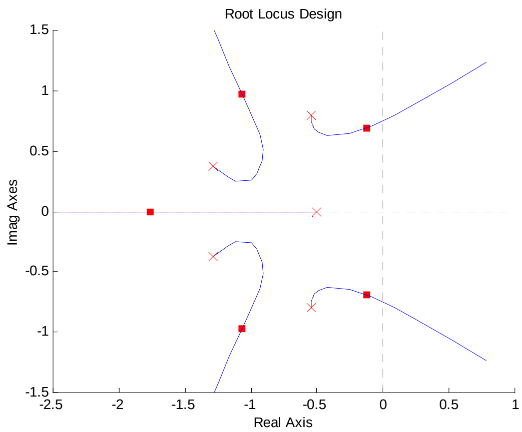
As τ decreases, the relative stability increases. It means that trained operators can make a system stable maintaining good performance.

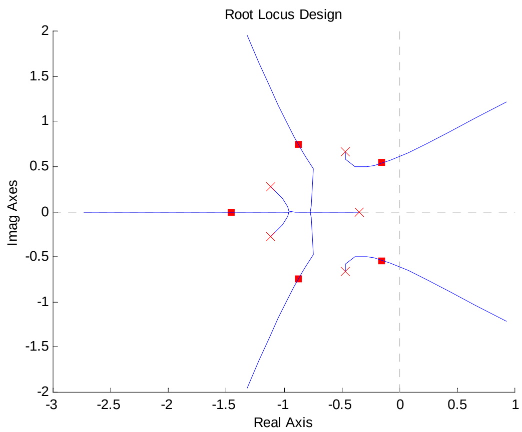
Let's consider the operating force to do job. Here, we define the operability as how operators easily do a given job and the index as u/x_s. It is the inverse of Eq.(1).

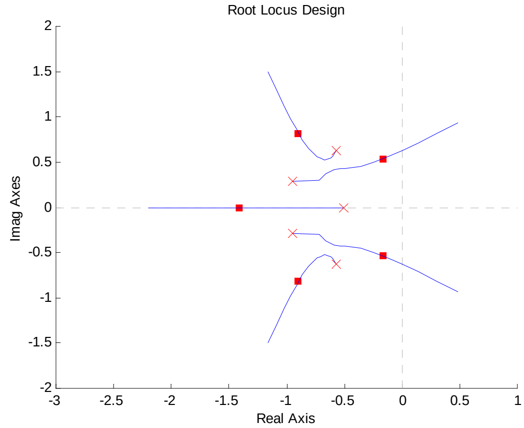
$$\frac{u}{x_s} = (m_1 + m_2)s^2 + cs + k_e \tag{5}$$

The interactive force is significant for small s, and the inertia is significant for large s. m_2 has to be as light as possible and strong enough. There is no way to reduce the interactive force.

The second one of Figure 3. There can be several root loci as the followings :







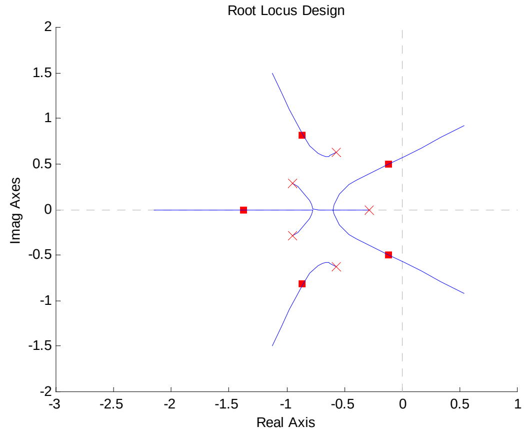


Fig. 6 Possible Root loci of Eq.(1.b).

The operability for the system is

$$\frac{u}{x_s} = \frac{(m_1 s^2 + c_1 s + k_1)(m_2 s^2 + c_2 s + (k_1 + k_e)) - k_1^2}{k_1} \tag{6}$$

The flexibility k_1 between the input device and machine can reduce the inertia load (s ≠ 0) but the effect is not too much. And as k_1 increase, the system becomes less stable. The static load (s = 0) is not affected by k_1.

The third one of Figure 3. The root loci is similar to Figure 6. And the role of trained operators is similar to the first one. The operability is

$$\frac{u}{x_s} = \frac{(m_1 s^2 + c_1 s + k_1)(m_2 s^2 + c_2 s + k_e) + k_e k_{FR} k_c}{k_c} \tag{7}$$

The force reflection ratio k_{FR} is important. The static load can be reduced by reducing the ratio. But a very small ratio means that the feedback loop of Figure 4 is not closed. Then the work may be very difficult.

4. CONCLUSION

Man-machine systems have been analyzed from the viewpoint of the operability. Three examples have been presented. The servo actuating system has an advantage to reduce static loads by adjusting the force reflection ratio. These are useful to design man-machine systems.

ACKNOWLEDGMENTS

This research has been carried out as a part of the nuclear R&D program funded by the Ministry of Science and Technology in Korea.

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