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ANALYSIS OF HUMAN VISUAL, FORCE AND AUDIO SENSORY FEEDBACK INTEGRATION IN MANIPULATION TASK

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Abstract: In most of the cases the lack of appropriate sensory feedback, as limited visual information and/or absence of force feedback, became a barrier to the widespread use of master-slave robotic systems. The analysis of how the human operator attains and processes the sensory feedback information is of great importance in the design of such teleoperated systems. The aim of this research is to analyze the human visual, force and audio sensory feedback integration related to a manipulation task. The result of this analysis will be used to build a model of a human operator in order to assist the design, simulation and evaluation of human-machine systems.

Keywords: Sensory Feedback, Human-Machine Control Characteristics, Human Control Model

1. INTRODUCTION

Nowadays teleoperated robots have been used from hazardous environments like nuclear power plants and undersea maintenance activities to very delicate operations like endoscopic surgery and micro manipulation [1]. However, in most of the cases the lack of appropriate sensory feedback, as limited visual information and/or absence of force feedback, became a barrier to the widespread use of master-slave robotic systems because the operator cannot be confident about the nature of the manipulated environment. To understand how the human operator, which is the most important element in a teleoperated system, analyzes and processes the sensory feedback information is of great importance to attain a remote controlled system as reliable as a direct manipulation. The aim of this research is to analyze the human control characteristics in respect to the visual, force and audio feedback information and build a human control model that can also represent a controller based on sensory feedback fusion. This human control model would be useful to assist the design, simulation and evaluation of human-machine systems like telerobots and also computer assisted systems as power-assist and drive-by-wire vehicles.

2. SENSORY FEEDBACK INFORMATION RELATED TO TRACKING TASKS

Many studies in the area of visual tracking have been done to understand the human control characteristics due to visual feedback information. However, quite a few researches have been conducted in the field of force and audio feedback information with the objective of analyze how the human operator makes use of this sensory feedback information in a manipulation task.

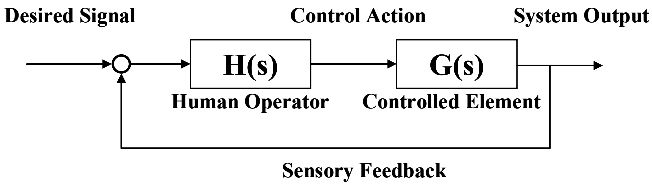

Fig. 1 General Human-Machine System with Sensory Feedback

2.1. Visual Feedback

Early researches have already shown that it is important to consider the human dynamic characteristics when designing and evaluating man-machines systems. The major part of the analytical theory on manual control of vehicles was developed in the 60's. One of the important results was the Crossover Model proposed by McRuer et al. [2]. It was shown that near the crossover frequency, which corresponds to H(s)G(s)=1 , the following equation was satisfied. (Fig. 1)

$$H(j\omega)G(j\omega) \approx \frac{\omega_c e^{-\tau j\omega}}{j\omega} \quad (\omega \cong \omega_c) \tag{1}$$

τ (0.1～0.4s) : Time lag due to human responses
ω_c (0.5～0.8 Hz) : Crossover frequency

According to the manipulated machine characteristics the human operator can modify his/her own dynamic characteristics so as the open-loop transfer function remains a first order system.

2.2. Force Feedback

The force feedback felt by the human operator is a result of a combination of tactile sensors and proprioceptive feedback. The Pacinian corpuscle, Ruffini Endings and the

Meissner's Corpuscle are responsible for the tactile sensation, while the muscle spindles and the Golgi tendons are related to the muscle's length/velocity and tension respectively [3]. Although the individuals properties of each sensor have been studied, how the human operator uses those information and how they affect the human control characteristics are still not well known. However, it is of general agreement that the force feedback information is very important to identify the controlled object properties, so that the human can build an internal model of it.

2.3. Audio Feedback

A primary function of audio feedback is said to direct the eyes to the source of the sound [4]. More specifically in a tracking task the audio feedback provides information about the localization and velocity of the moving target. Although the space discrimination of auditory localization is not so accurate (about 15 degrees) compared to the visual, it provides a supplementary information to assist others sensory feedback.

3. HUMAN-MACHINE MODELS

In a general human-machine system represented in Fig. 1, the human operator based on a reference signal, which can be internal or external to him, manipulates the controlled object according to the observation of the system's output acquired by the sensory feedback information mentioned before. After some practice it can be noted an improvement in the manipulation performance. This improvement might be associated to an acquisition by the human operator of an internal model of the controlled element represented by an inverse model in Fig. 2. This idea is expressed by McRuer et al. [5] as an acquisition of a familiarity with the vehicle dynamics. In a similar way Kawato [6] proposed a feedback-error-learning scheme to explain the motor learning strategy related to human body. Despite the controlled element is different in both case the basic concept is quite similar. Kawato's model shows that in the beginning stage of motor learning the feedback torque τ_{fb} are predominant over the feedforward torque τ_{ff} , in a similar way that McRuer pointed out in a driving task where the controlled object is a car. In these both cases the existence of appropriate feedback information is of a great importance in order to build an internal model. However, when a human operator is performing a manipulation task, he receives various kinds of information like visual, audio and force feedback at the same time. Therefore, the analysis of the human control characteristic due to these sensories feedback information is crucial to understand the acquisition of an internal model by the human operator. As a preliminary stage, a selection of a task that permits the analysis of these sensories feedback information independently is very important. Next, the proposed task will be described.

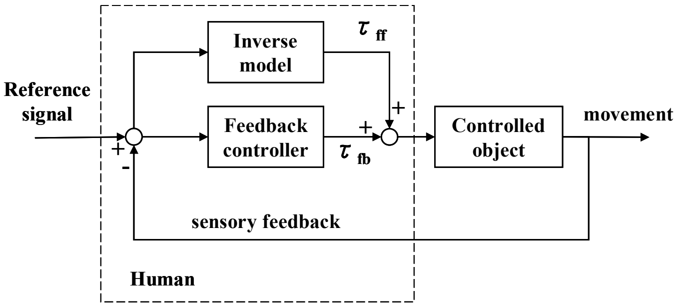

Fig. 2 Human-Machine Control Model

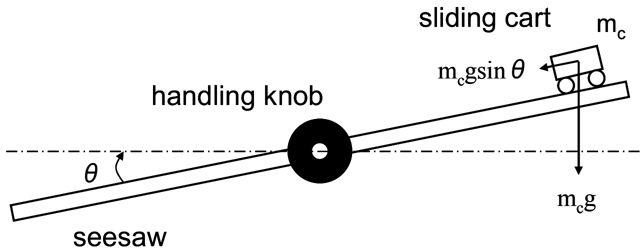

Fig. 3 Seesaw and Sliding Cart Overview

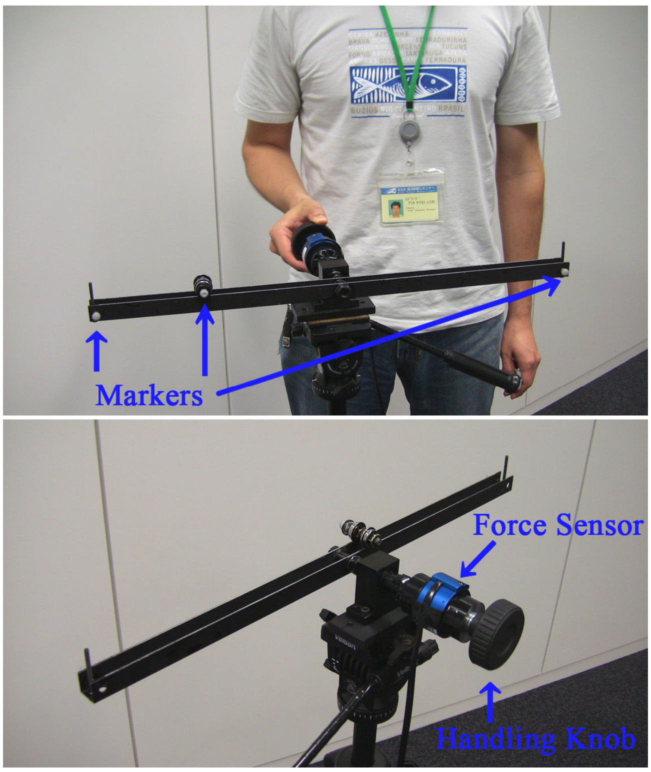

Fig. 4 Mechanical Type Seesaw Experimental Device

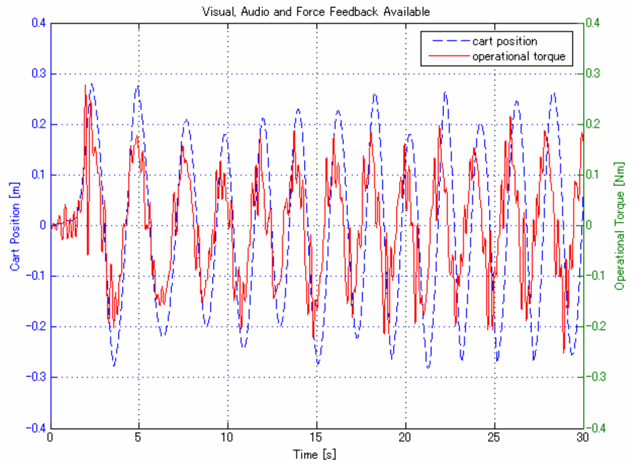

Fig. 5 Task executed in the presence of visual, audio and force feedback information

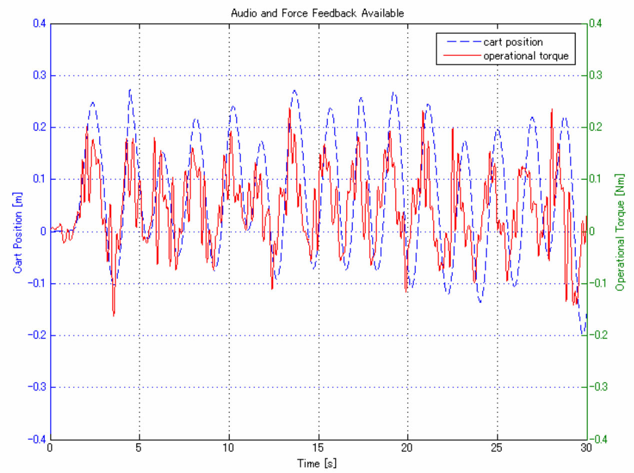

Fig. 6 Task executed in the presence of audio and force feedback information

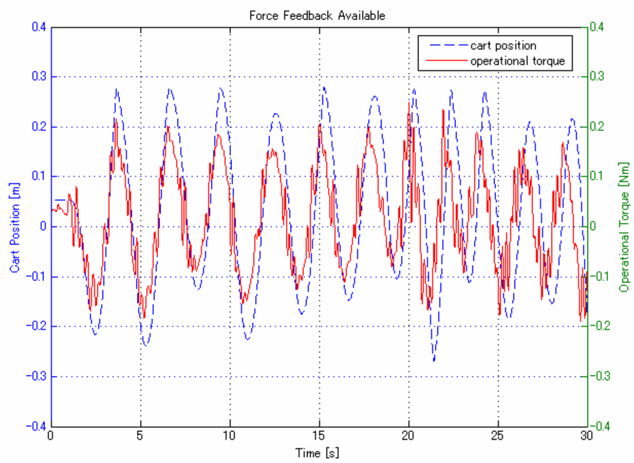

Fig. 7 Task executed in the presence of force feedback information

3. EXPERIMENT

3.1. Overview

In order to analyze the human sensory feedback properties independently, a SEsaw Experimental Device (SEED) was proposed in this preliminary stage (Fig. 3). It consists of a straight beam (600mm) that serves as a seesaw and a sliding cart that moves over the seesaw. The human operator manipulates the SEED by handling a knob with a 6-axis force sensor (IFS-50M Nitta Corporation) attached to it and turning it clockwise or counter-clockwise in order to move the sliding cart from one side to another. Some small retro-reflective markers were attached to the seesaw and the sliding cart and its movements were measured using a VICON Motion Capture System (Vicon Peak Company) (Fig. 4).

3.3. Experimental Task

First, in the case of analyzing the human visual feedback properties, the human operator had to manipulate the master device in order to make the sliding object move from one side to another trying to reach a total stroke of 500mm. There was no instruction about the movement frequency. The torque due the dislocation of the sliding object can be felt by the human operator through the handling knob and the sliding sound is also available. This task will be called VAF (visual, audio and force feedback available).

Next, to analyze the human control properties due to the audio and force feedback information, the operator was asked to close his eyes and orientated to move the sliding object as the same amplitude and frequency as the previous task. In this case, the audio feedback that is proportional to the sliding cart's velocity and the force between his hand and the knob are felt by the operator. This task will be called AF (audio, force feedback available).

Finally, the human control characteristics due to the force feedback information solely were analyzed blocking the visual and audio feedback information. The operator manipulated the handling knob in order to dislocate the sliding object in the same way as the two tasks before with information about only the force sensed through the handling knob. The sound of the sliding cart was shut off by providing the subject with a headphone and playing music in quite loud volume. This task will be called F (only force feedback available).

Despite the VAF task includes audio and force feedback information, it was executed essentially based on visual information. This issue will be discussed later.

In these preliminary experiments using a mechanical SEED, it was not possible to separately complete the three types of feedback information. The development of the next prototype, which is a master-slave type SEED, is almost completed and the execution of the task which only visual feedback is available will be possible.

After analyzing the three control characteristics based on visual [Hv(s)], force [Hf(s)] and audio [Ha(s)] sensory feedback information separately, various sensory feedback modality will be provided to the operator in order to build a human control model with multiple sensory feedback information (Fig. 8). The human-machine control characteristics analysis will be based on system identification methods to determine each transfer function form and parameters [7].

3.4. Experimental Results

The operational torque data was filtered using a low pass band second order Butterworth filter with a cutoff frequency of 5Hz.

From the experiments results of tasks VAF, AF and F (Fig. 5, 6, 7), it can be noticed that despite the absence of visual feedback information all the three tasks were performed successfully with almost the same amplitude and frequency. To evaluate the maneuverability of each task the following operational proficiency was defined:

$$\rho = \frac{\int |T_o| dt}{\int |x_c| dt}$$

where:
T_o : operational torque
x_c : cart position

This operational proficiency index represents how much effort it was applied to executed a determined task.

According to this evaluation index the VAF task achieved the best performance ρ_{VAF} = 6.29 (σ =0.04). The following two tasks which were performed without any visual information presented almost the same level of maneuverability, ρ_{AF} = 6.8 (σ =0.2) and ρ_F = 6.76 (σ =0.04). The subject that performed the tasks mentioned that the main information relied in VAF was the visual and in task AF was the audio. This observation is supported by the low level of noise in the operational torque in F task.

5. DISCUSSION

In this preliminary experiment using a mechanical SEED it was demonstrated that it was possible to control the sliding cart with just one of the feedback information modality. And it was also verified that exists a predominance of one sensory feedback modality about another. However, it is important to notice that the subject could possibly acquire the internal model of the SEED in task VAF. This made it possible to execute task AF and F. How the human operator acquires an internal model from the sensory feedback information will be the theme of future experiments.

6. FUTURE WORKS

The next step is to build a human sensory feedback integration model to represent the human operator control characteristics which is intended to be used in the design, evaluation and improvement of human-machine systems like master-slave robots.

Furthermore, in order to analyze the human sensory feedback modalities completely separately a Master-Slave type seesaw experimental device has been developed and the results using the new MS-SEED will be presented at the congress. It consists of a 1 DOF master haptic device with a force sensor that can be manipulated by rotating an actuated knob. The slave is an actuated linear guide that works as a seesaw with a sliding object over it. (Fig. 9)

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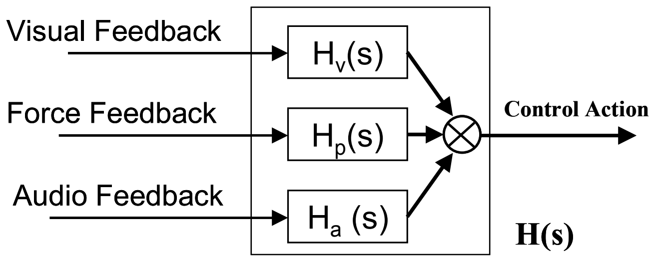

Fig. 8 Sensory Feedback Integration in Manipulation Task

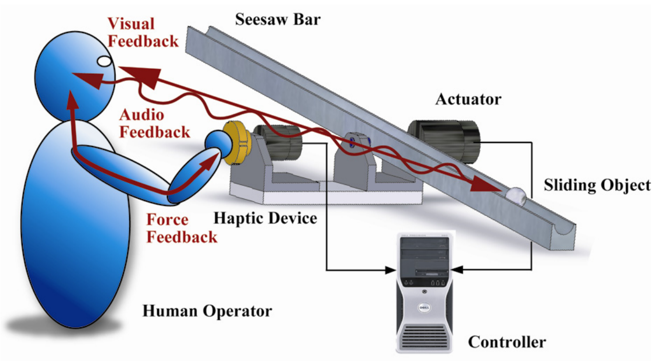

Fig. 9 Master-Slave Type Seesaw Experimental Device (MS-SEED)