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論 文 要 旨

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1.Introduction

When using the impedance-adjusting bilateral control to provide a force-feedback function to a master-slave system. The system parameters are often adjusted for the requirements of different tasks. Besides the task requirements, the human factors should also be considered when adjusting system parameters. The operator’s haptic sensation, which means “how easily an operator can sense the contact between the slave device and the environment”, is an important human factor. However, it is often weakened after an impropriate system parameters adjustment.

Therefore, a system parameters design requires the consideration of both the task requirements and the haptic sensation. However, the related works cannot provide such a method. Thus the system parameters design considering both the two factors are conducted by an unfounded method: the trial and error adjustment.

To address this problem, the objective of this study is to build a method of system parameters design considering both the operator’s haptic sensation and the task requirements. Specifically, the main task of this study is to quantify the relationship between the system parameters and the operator’s haptic sensation. In this study, the task is accomplished by the following two steps: 1. proposing an index to quantify the haptic sensation; 2. finding its relationship to the system parameters.

2.An index of operator’s haptic sensation

This chapter summarizes the first step: proposing an index to quantify the haptic sensation.

Based on the analysis on operator’s sensing mechanism, an index being hypothesized to quantify the operator’s haptic sensation is defined, its value is calculated from the change magnitude of the master device velocity over 20-30ms before and after contact. The name of the index is “Dynamic Contrast (C)”.

Because the operator’s haptic sensations do not change with different contact velocities if other conditions are constant, the index values under one condition should be stable to different master velocity before contact. An experiment was conducted to check this index property. The experimental results showed that, under every operation condition, the coefficients of variation from index values with different contact velocities are less than 15%. The proposed index is stable to different master velocity before contact.

The system parameter designer often expects to know a sensation is strengthened or weakened while considering the haptic sensation. Thus when using the proposed index to quantify the haptic sensation, the system parameter designer also expected to know to which rate the index changes can make an operator’s real sensation different. A psychophysics experiment was conducted to clarify this point, the experimental results showed that the necessary change rate to make a different sensation is not constant. It can be calculated from the reference index value.

Next, another psychophysics experiment was conducted to check whether the proposed index value can represent the operator’s haptic sensation correctly. The experimental results showed that the relationship of the haptic sensations for any different parameter combinations fitted the prediction solely based on their index values, which means the proposed index is valid to quantify the operator’s haptic sensation.

3.The relationship between the index and the system parameters

This chapter summarizes the second step: finding the relationship between the haptic sensation index and the system parameters and expressing it as a mathematical function.

For the ideal bilateral control model that considering the connection between the master and the slave devices as a virtual rigid body, a function that calculates the master velocity from the system parameters

is derived by solving the control model's equations of motion. As the index is defined from the master velocity, after substituting the master velocity function into the index definition, the mathematical function that shows the relationship between the haptic sensation index and the system parameters was obtained.

In real application of bilateral control, the virtual rigid body that connects the master and the slave devices is often considered as a virtual impedance (determined by two impedance parameters). From the simulation results under multiple parameter combinations, the effect from the two impedance parameters can be considered as a coefficient to the index value of the ideal bilateral control model. Hence, the mathematical function for the real application bilateral control model was obtained by first fitting the function that calculates the virtual impedance parameters' effect coefficient, and second multiplying the coefficient with the index function derived for the ideal control model.

The index value can be directly calculated from the system parameters by the mathematical function.

4. Applications as a guideline for system parameter design

This chapter shows a system parameters design case using the results of the previous two chapters. For an application case that both the task requirement and the operator's haptic sensation should be considered, the parameters designer first adjusted the system parameters to satisfy the task requirement, then he used the relationship function of the haptic sensation and the system parameters to calculate the necessary value of other parameters, which can provide a desirable haptic sensation to the operator. The system parameters design was confirmed valid by experimental results.

5. Conclusion and Future works

This chapter summarizes all this study, and proposes some topics to address in the future.