HAND MOVEMENT IMPROVEMENT ON VISUAL TARGET TRACKING BY MODEL-BASED COMPENSATOR

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Abstract: Brain dysfunction in the cerebral cortex, cerebellum and/or basal ganglia causes serious movement disorders such as cerebellar ataxia, Parkinson disease and so on. Compensation of hand movement by adding an external force will recover the motor function and will be helpful for improving the quality of patients' daily life. This paper proposes a method for compensating human hand movement on visual target tracking by adding an assistant force. Mathematical model was obtained from the measurement data of visual target tracking for each subject, and the compensator was constructed based on the model. Effectiveness of the compensation method was investigated through the experiment.

Keywords: Hand Movement Compensation, Visual Target Tracking, Modeling, Assistant Force, Model-Based Compensator, Movement disorders

1. INTRODUCTION

Generation of appropriate motor commands by central nerve system practices the realization of dynamic and skillful motion of human (Rothwell, 1994). Motor and supplemental motor area in cerebral cortex, basal ganglia, cerebellum and so on have great contribution for realizing accurate motor control (Ito, 2000; Rothwell, 1994). Serious defects in motor control occur when the cerebellum or the basal ganglia has injured. Movement disorder originating from the cerebellum such as cerebellar ataxia develops a lack of accurate movement and troubles in motor learning. Symptom of movement disorder in the basal ganglia such as Parkinson disease is the delay of reaction and no smooth change of the motion.

A technique for modifying the hand movement by adding assistant force is effective for such patients with various movement disorders. Development of active orthosis for improving an accuracy of hand movement will be useful for recovering a quality of patients' daily life.

A test of visual target tracking is one of the effective methods for analyzing the human motor functions (Ide *et al.*, 2000; Richter *et al.*, 2004; Vercher and Zgauthier, 1992). We have previously reported

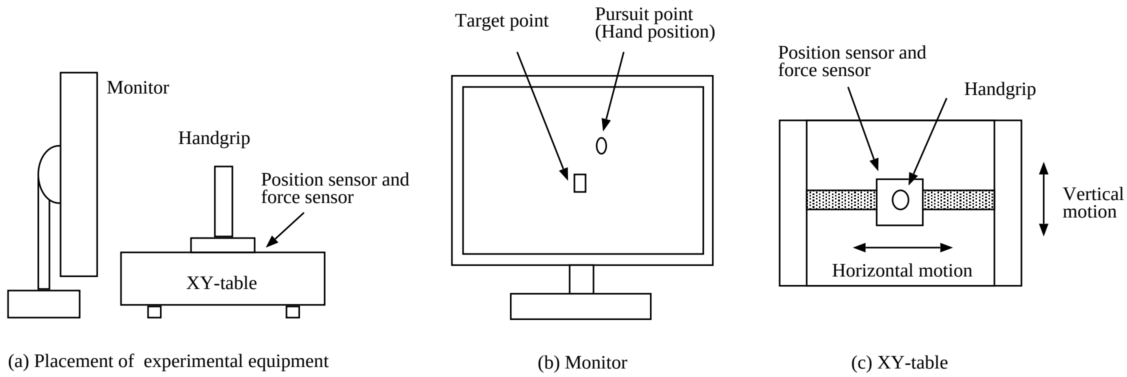

Fig. 1. Experimental equipment for hand movement compensation on visual target tracking. Subject holds a handgrip and then a pursuit point on the monitor moves according to the motion of handgrip. Two servo motors equipped in the XY-table generate the assistant force for the hand movement compensation.

the quantitative evaluation on the relationship between movement disorders and the characteristics of motor functions (Ide *et al.*, 2000). Then, the characteristics of hand movement of the patients with movement disorders were expressed by the model, and the differences among normal subjects, patients with cerebellar ataxia and patients with Parkinson disease could be found in the model parameters (Sugi *et al.*, 2002). A possibility on improving the hand movement by additional assistant force was also investigated through a simulation study (Bai *et al.*, 2001; Sugi *et al.*, 2003).

In this paper, the method for compensating the hand movement on visual target tracking was examined through the experiments. First of all, a mathematical model for expressing the property of human hand movement was obtained from the measurement data of visual target tracking for each subject. Then, the compensator of hand movement was constructed by using the information of model structure. Proposed method was applied to four healthy adults, and the effectiveness of the hand movement compensation technique was quantitatively investigated

2. METHOD

2.1 Experimental equipment and visual target tracking

The experimental equipment for measuring the visual target tracking and for hand movement compensation used in this study is shown in Figure 1. The system consists of personal computer (NEC PC-9801Xa), monitor and XY-table (RIKEN DENSHI F45) with a handgrip (Figure 1(a)). XY-table equips force sensors and position sensors in the base of handgrip and those values are transmitted to the computer through A/D converter. XY-table also has two servo motors for moving the base of handgrip both horizontally and vertically, and control inputs as compensation signal for hand movement compensation are given from the computer to the servo motor through D/A converter (Figure 1(c)). Subject holds on a handgrip by his/her hand and moves it, just then the corresponding green circle point (pursuit point) is moved on the monitor. Visual target with red rectangular is also displayed on the same monitor (Figure 1(b)). Subject carries out the task to pursue the visual target as correctly and speedily as possible by moving a handgrip on XY-table.

Visual target used in the experiment moves 3 sec long from the upper part to the lower part of the monitor straightforwardly with a constant speed of 3 cm/s. Number of subjects were four healthy adults and number of trials of visual tracking test was continuously 20 times for each subject. After the measurement of visual target tracking, the mathematical model was obtained. Then, the compensator for hand movement based on the model was constructed. Then, the experiment of visual target tracking by adopting hand movement compensation was done with a same measurement condition.

2.2 Modeling of human hand movement

Properties of the hand movement on visual target tracking was expressed by mathematical model. The model structure adopted in this study is shown in Figure 2(a). $P_r(s)$ as input signal for the system means the position of visual target and $P_h(s)$ as output signal of the system denotes the hand position of subject. Model structure was based on the second order mechatoronic servo model with time delay (Bai *et al.*, 2001). Transfer function of the model shown in Figure 2(a) can be expressed as

$$G(s) = \frac{K_p K_v}{s^2 + K_v s + K_p K_v} e^{-Ls} \tag{1}$$

where L means the reaction delay, K_p is the position loop gain and K_v is the velocity loop gain. Model structure is simple, but can grasp the characteristic of hand movement for normal subjects, patients with cerebellar ataxia and patients with Parkinson disease sufficiently (Bai *et al.*, 2001). Parameters L, K_p and K_v in the model was determined by using the least squares method.

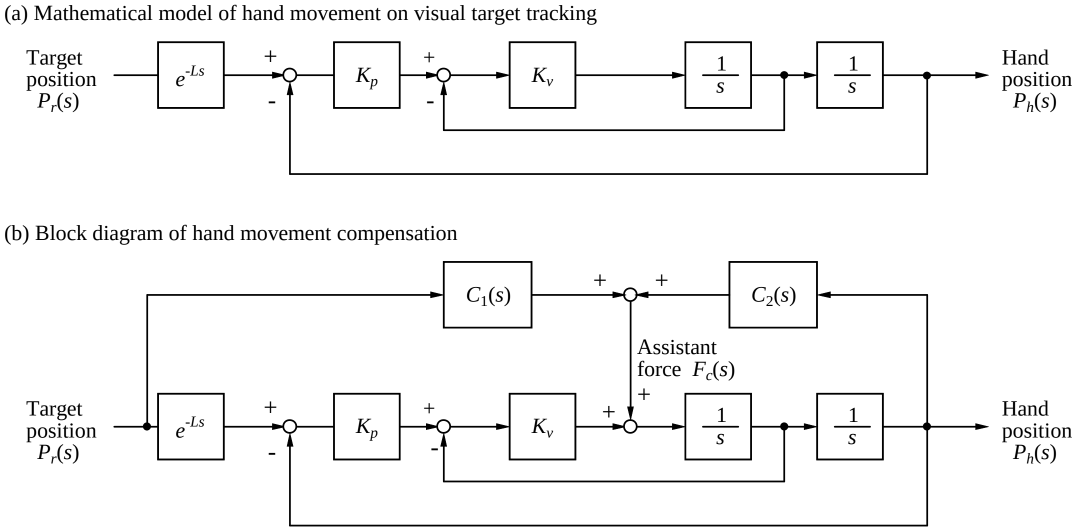

Fig. 2. (a) Model structure of visual target tracking, and (b) Block diagram for hand movement compensation. Characteristics of the hand movement was expressed by the mechatoronic servo model with time delay. Model-based compensator $C_1(s)$ and $C_2(s)$ generate the assistant force.

2.3 Construction of hand movement compensator based on model

Compensator of hand movement on visual target tracking was then constructed by using the model information. Block diagram for the hand movement compensation is shown in Figure 2(b). Compensator consists of two blocks $C_1(s)$ and $C_2(s)$, and the compensation signal $F_c(s)$ as assistant force is calculated by the summation of those outputs. Therefore, the equation for generating additional assistant force can be expressed as

$$F_c(s) = C_1(s)P_r(s) + C_2(s)P_h(s) \qquad (2)$$

Transfer function of the total system including compensator $C_1(s)$ and $C_2(s)$ shown in Figure 2(b) is calculated as

$$G^a(s) = \frac{K_pK_ve^{-Ls} + C_1(s)}{s^2 + K_vs + K_pK_v - C_2(s)} \qquad (3)$$

The structure of transfer functions $C_1(s)$ and $C_2(s)$ were designed in the following way. First of all, the referential model, which executed the ideal movement on visual target tracking, was established as same structure of eq. 1 as

$$G^\dagger(s) = \frac{K_p^\dagger K_v^\dagger}{s^2 + K_v^\dagger s + K_p^\dagger K_v^\dagger} e^{-L^\dagger s} \qquad (4)$$

where $L^\dagger$, $K_p^\dagger$ and $K_v^\dagger$ are the parameters and can be adjusted freely. Transfer functions $C_1(s)$ and $C_2(s)$ were then determined by solving the following equation as

$$G^a(s) = G^\dagger(s) \qquad (5)$$

In this study, transfer functions $C_1(s)$ and $C_2(s)$ were settled as

$$C_1(s) = -K_pK_ve^{-Ls} + K_p^\dagger K_v^\dagger e^{-L^\dagger s} \qquad (6)$$

$$C_2(s) = (K_v - K_v^\dagger)s + K_pK_v - K_p^\dagger K_v^\dagger \qquad (7)$$

Transfer function $C_1(s)$ includes the component of reaction delay, so the $C_1(s)$ mainly compensates the quickness of the reaction of the hand movement. Transfer function $C_2(s)$ compensates the other dynamical properties such as smoothness, changes of the motion and so on.

2.4 Evaluation of hand movement compensation

In order to evaluate the effectiveness of the hand movement compensation quantitatively, the following parameters were calculated from the experimental data. First, the reaction time was defined by the time difference of the beginning of movement between visual target and pursuit point. Secondly, the position error e_p was defined as

$$e_p = \frac{1}{T}\int_0^T (p_r(t) - p_h(t))^2 dt \qquad (8)$$

where $p_r(t)$ and $p_h(t)$ were the vertical movement of the visual target and the hand position (pursuit point), respectively. T was the calculation interval (3 s). Thirdly, standard deviation of the velocity for vertical direction v_d was calculated as

$$v_d = \frac{1}{T - T_1}\int_{T_1}^T \left(\frac{dp_h(t)}{dt} - \bar{v}_h\right)^2 dt \qquad (9)$$

T_1 defined a middle time of interval T (1.5 s), and $\bar{v}_h$ was an average of hand velocity $dp_h(t)/dt$ in the calculation interval T_1 and T. The above three parameters adopted in this study were already established as useful ones for extracting the properties of the hand movement on visual target tracking in the previous study (Ide *et al.*, 2000). In addition to the above three parameters, the jerk for vertical hand movement was obtained as

$$f_j = \frac{1}{T}\int_0^T (\frac{d^3 p(t)}{dt^3})^2 dt \tag{10}$$

Differences between experimental data with the hand movement compensation and that without hand movement compensation were verified quantitatively by comparing the above four characteristic parameters.

3. RESULT

3.1 Modeling of visual target tracking

An example for the comparison between the model output and the actual measurement data of hand movement on visual target tracking was indicated in Figure 3. Gray solid line shows the target trajectory, black solid line is the measurement data (pursuit trajectory) and black broken line is the model output. Waveform of the model output was good agreement with that of actual measurement data enough.

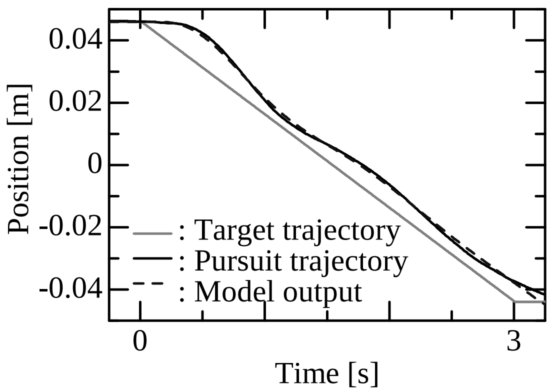

Fig. 3. Comparison of visual target tracking between model output and actual measurement data. Characteristic of model output was coincided with the measurement data.

As a result of modeling the hand movement for all data, 78 models out of 80 (4 subjects × 20 trials) were well coincided with the characteristics of the measurement data. Accordingly, the 78 models were used for constructing the compensator. Mean value of the model parameters L, K_p and K_v for each subject were shown in Table 1. Value of those parameters were similar for four subjects.

Table 1. Mean values of model parameters L, K_p and K_v obtained from the measurement data for each subject.

Parameters	L	K_p	K_v
Subject 1	0.25	7.0	1.2
Subject 2	0.25	8.0	1.2
Subject 3	0.25	7.9	1.1
Subject 4	0.26	8.0	1.1

3.2 Hand movement compensation

Hand movement compensator for each subject was constructed by using the parameters shown in Table 1 and those of referential model expressed as eq. (3). In this experiment, values of the parameters in the referential model were set at $K_p^\dagger$=2.5, $K_v^\dagger$=12.5 and $L^\dagger$=0.1, respectively. Experimental result of the hand movement compensation was shown in Figure 4. Left hand side shows the result of visual target tracking without adopting the hand movement compensation (Figure 4 (a)), and right hand side is that with compensation (Figure 4 (b)). Upper part means the hand position (a-1 and b-1), middle part is the velocity (a-2 and b-2), and lower part is the contact force between human hand and handgrip (a-3 and b-3). Force of human hand, additional assistant force by the compensator and total force were independently displayed in the figure concerning the result with compensation (b-3). Reaction time, position error and variability of the velocity of the result with compensation were precisely reduced as compared with that without hand movement compensation. Assistant force had an effect especially in the beginning of hand movement.

Figure 5 shows the comparison of the characteristic parameters defined in the previous section between the result of visual target tracking without compensation and that with compensation. Mean value and standard deviation of respective parameters for all data and those for each subject were displayed. Gray bar shows the parameter values obtained from the data without hand movement compensation and black bar denotes those with hand movement compensation. Sufficient improvement of the hand movement compensation could be found through the comparion of four parameters.

4. DISCUSSION

4.1 Model structure

Skillful motor control of human is achieved by the appropriate motor commands generating from the central nerve system. Several regions in human brain are concerned with the achievement of motor control. In particular, the cerebellum and the basal ganglia have an important role in motor control (Rothwell, 1994; Ito, 2000). Internal predictive model may exist in the cerebellum and contributes the accurate motor control

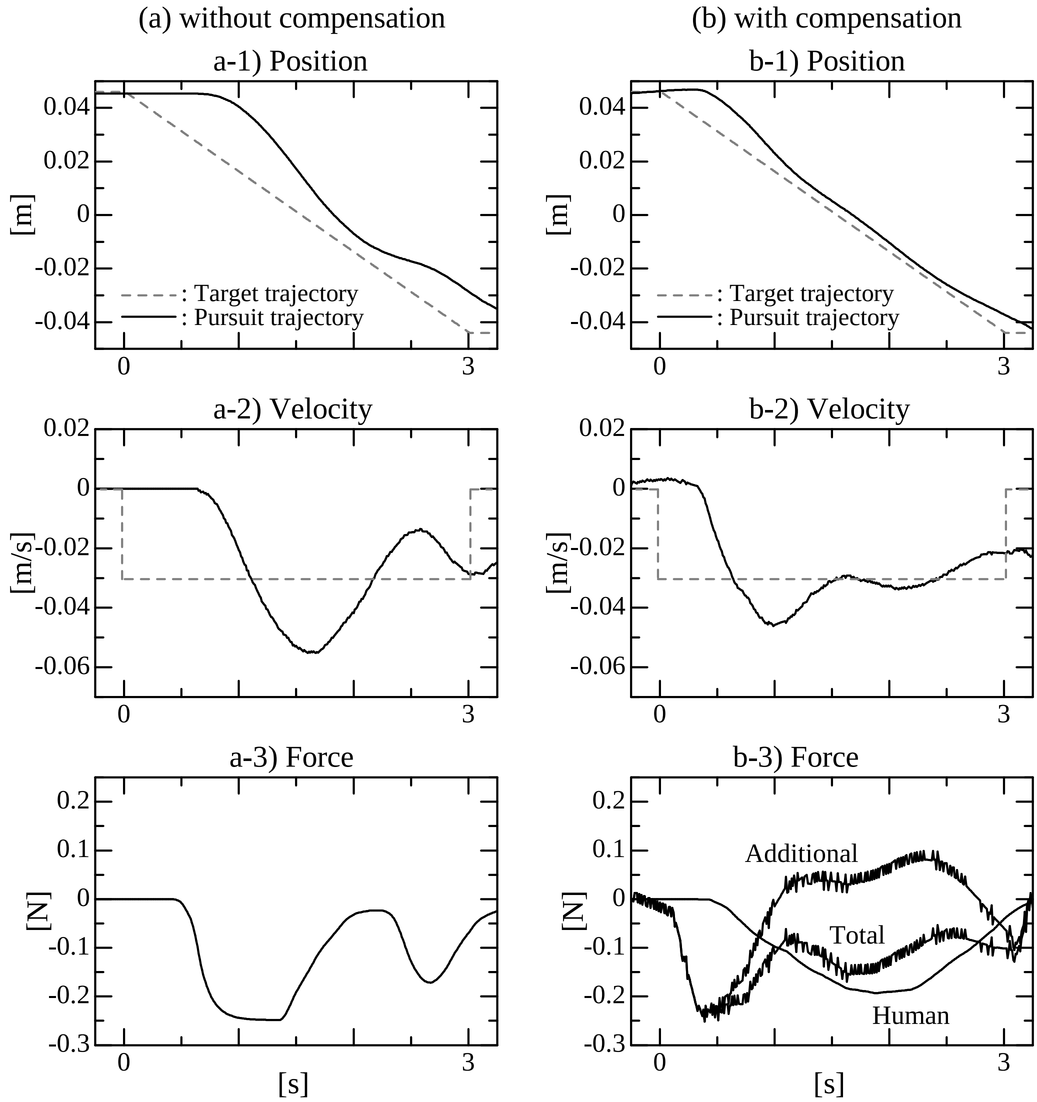

Fig. 4. Comparison of the experimental result for the hand movement compensation. (a) Visual target tracking without adopting the hand movement compensation, and (b) that with the hand movement compensation. Position, velocity and force of human hand were displayed.

(Ito, 2000). The model based on the motor control apparatus of human has been proposed by many researchers (Sanner and Kosha, 1999; Kawato *et al.*, 1987; Miall *et al.*, 1993). Kawato *et al.* proposed a combinational model of inverse dynamic representation and negative feedback loop (Kawato *et al.*, 1987). Miall *et al.* proposed a representation of the internal model in the cerebellum as the Smith predictor (Miall *et al.*, 1993). Authors have also studied such kind of model structure concerning the motor control of human in the past (Sugi *et al.*, 2002). Model structure on visual target tracking adopted in this study does not directly correspond to the motor control apparatus concerning the human brain function (Bai *et al.*, 2001). Therefore, the meaning or interpretation of the parameters in the model were difficult from the neurophysiological point of view. However, the purpose of the model is not only the elucidation of the human brain function, but also is for constructing the hand movement compensator. Consequently, the model structure can be regarded as an appropriate for the usage of hand movement compensation.

4.2 *Stability of compensator*

In the proposed method, compensator was constructed by using the model information obtained from the measurement data of visual target tracking. Generally, the obtained model often includes the modeling error, so the influence of modeling error should be taken into account. In this study, the stability of the compensator was proved by the Rauth method under the contamination with modeling error and unpredictable disturbance. In addition to the above result, the stability of the proposed compensator was also ascertained through the simulation study. At the experimental results for the total 80 trials on four subjects, unstable motion or continuous oscillation were not observed in the hand movement compensation at all.

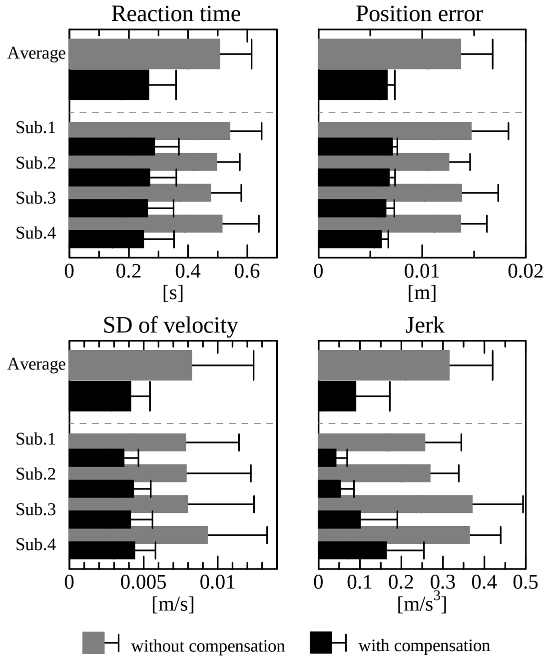

Fig. 5. Quantitative evaluation of hand movent compensation. Accuracy of the hand movement on visual target tracking was improved by the model-based compensator.

To consider the avobe results, the proposed model-based compensator has enough robustness and stability for the modeling error and the unpredictable disturbance.

4.3 Application

Deterioration of the motor function is completely different for respective patients with movement disorders, and depends on a degree and/or a kind of the brain dysfunction. The hand movement compensation method proposed in this study was constructed by using the measurement data on visual target tracking for each subject. So the properties of the hand movement for different subjects can be reflected in the structure of the compensator. Therefore, the proposed method is easily adjustable to the individual properties of patients with various movement disorders.

5. CONCLUSION

This study proposed a method for improving the hand movement on visual target tracking by additional assistant force. Based on the experimental data of visual target tracking, characteristics of the hand movement was extracted by the mathematical model. Then, the compensator was constructed. Sufficient improvement of hand movement was verified through the experiment for four subjects. Proposed compensation technique will be effective for assisting the movement of patients with various movement disorders caused from brain dysfunction.

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