Passive Haptics: Variable Asperity by Using Damping Brake of DC Motor

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***Abstract*—A passive haptic interface that is inherently safe and stable and can present variable virtual asperity was developed. This interface delivers passive resistance force by switching on and off the damping brake of a DC motor without being driven. We conducted identification experiments for six levels of asperity stimuli to investigate human perceptual properties against passive asperity. Variable asperity was found to be successfully discriminated into several levels at approximately 70%. Furthermore, information transfer was calculated to be 1.60 bits.**

I. Introduction

Haptic interfaces, wherein the hardware itself comprises passive elements, have the advantage of inherent safety, energy efficiency, and low-cost. Such haptic interfaces have been developed thus far [1], and are expected to be applied in virtual reality systems, which may be used by a number of unspecified users. We developed a passive haptic interface based on the damping brake of a DC motor [2], [3]. The device can present surface asperity using the resistive force of the damping brake. The asperity is varied by changing the intervals of presentation of the brakes. Applications of such asperity stimuli include force feedback for steering wheels to convey information about road conditions to drivers and force feedback for dial controllers to adjust the volume. Thus far, the characteristics of human perception of asperity stimuli presented by a periodic resistance force have been investigated [4]. In the research, the main purpose was to specify the parameters that influence the perception of asperity. On the other hand, discrimination characteristics of stimuli are important for accurate information transmission. However, identification experiments or the investigation of the discrimination thresholds of asperity stimuli presented by passive haptic interfaces have not been conducted. In this study, we performed an identification experiment for six levels of asperity stimuli to investigate the utility of passive asperity stimuli as tools for information transmission.

II. Passive haptic interface using damping brake of DC motor

Figure 1(a) shows a photograph of the haptic interface based on the damping brake of a DC motor. A DC motor was fixed on an aluminum frame and a crank with a handle was connected to its output shaft. Although this device uses a DC motor, it is not driven. The device uses only the brake force of the damping brake of the DC motor. The device presented force sensation passively by controlling the ON/OFF process of the damping brake while an operator rotated the crank attached to the motor. The ON/OFF process of the damping brake was controlled using the motor driver (See Fig. 1(b)), and the rotation angle of the motor was measured by an encoder mounted on the motor. As shown in Fig. 1(c), by switching the ON/OFF process of the brake at regular angular intervals, the braking and release of the operator's hand was repeated, and as a result, the operator perceived virtual asperity from the periodic force.

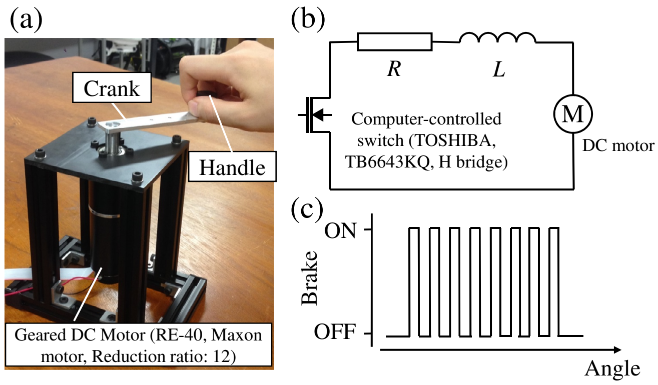

Fig. 1. Haptic interface based on the damping brake of a DC motor. (a) Overview of the device. (b) Short circuit of a DC motor controlled by switch. (c) Switch operation for presenting asperity stimuli.

III. Experiment

We conducted an identification experiment for six levels of asperity stimuli to investigate the discriminative ability of humans against the passive asperity stimuli.

A. Stimuli

Six levels of asperity stimuli were from S_1, which was the finest stimulus, to S_6, which was the coarsest stimulus. As the change in spatial frequency is dominant in the perception of asperity [4], we expressed different asperities by changing the spatial frequency of the ON/OFF process of the brake. Although our haptic interface can switch the ON/OFF process of the brake finely, such stimulus is too fine to be recognized as an asperity. Further, very long intervals of the brakes were not perceived as an asperity stimulus. Then, we decided the minimum and maximum intervals of brakes that can be perceived as asperity. The ON/OFF process of the brakes was repeated at intervals of 0.15 deg in S_1, and 7.3 deg in

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TABLE I
CORRECT ANSWER RATE AND INFORMATION TRANSFER.

Participants	A	B	C	D	E	Ave.
Correct answer rate (%)	68.3	65.8	73.3	69.2	81.7	71.7
Information transfer (bit)	1.58	1.32	1.68	1.55	1.88	1.60

TABLE II
AVERAGE CONFUSION MATRIX.

	R_1	R_2	R_3	R_4	R_5	R_6
S_1	0.67	0.33	0	0	0	0
S_2	0.04	0.5	0.45	0.01	0	0
S_3	0.02	0.18	0.61	0.18	0.01	0
S_4	0	0	0.11	0.81	0.08	0
S_5	0	0	0.01	0.25	0.71	0.03
S_6	0	0	0	0.02	0.14	0.84

S_6. We designed the remaining stimuli, S_2–S_5, as the spatial frequency of the ON/OFF process of the brakes increased linearly on the logarithmic axis from S_1 to S_6; that is, as the number of ON/OFF processes per rotation angle decreased in an equal ratio from S_1 to S_6.

B. Participants

The participants were five volunteers. Auditory cues were masked by headphones playing a pink noise during the experiment. The participants experienced asperity by rotating the crank at any speed.

C. Task

The participants performed the identification task for six levels of asperity stimuli. They identified the asperity of the stimulus by stating numbers 1–6. For each participant, the total number of trials was 120, including 20 trials for each of the six stimuli. We divided the experiment into 4 sessions; each had 30 trials, including 5 trials for each stimulus. The order of presented stimuli was randomized in each session. Before the first session, we conducted a 3 min training session for the participants to memorize each stimulus. In this session, they could experience the six types of stimuli as many times as they desired. Similarly, we also had a 1 min training session before the other sessions. Breaks of several minutes were given between each session.

D. Results

Table I indicates the correct answer rates for each participant. The correct answer rate was the highest for participant E with 81.7%, lowest for participant B with 65.8%, and the average rate was 71.7%. The experimental results were summarized in a 6 $\times$ 6 confusion matrix about the stimuli (S_1–S_6) and the responses (R_1–R_6). The average answer rates of the five participants are presented in Table II. Diagonal elements (S_i, R_i) indicate the probabilities that responses were coincident with the presented stimuli. We calculated the information transfer (IT) from the confusion matrix. The IT indicates the quantity of information transmitted by the received stimuli. The average IT is given by

$$IT = \sum_{i,j} P(S_i, R_j) \log_2 \left(\frac{P(S_i \mid R_j)}{P(S_i)} \right), \quad (1)$$

where $P(S_i)$ is the occurrence probability of S_i, $P(S_i,\ R_j)$ is the joint probability of S_i and R_j and $P(S_i \mid R_j)$ is the conditional probability of S_i given R_j. The average IT value for all participants was 1.60 bits.

E. Discussion

As the average IT value for asperity stimuli was 1.60 bits, our device can present at least three levels of identifiable asperity: $2^{1.60} \sim 3.0$. It is known that IT values depend on the experimental design [5]. Especially, the number of stimuli used in the experiment influences the IT values. The less number of stimuli may result in greater IT values. There may be room for increasing the IT value by rearranging the experimental conditions in terms of the number of stimuli.

IV. CONCLUSION

We investigated the characteristics of the human perception of asperity stimuli passively presented by the haptic interface. The average correct answer rate of identification experiments for six levels of asperity stimuli was 70%. Furthermore, the average IT value was 1.60 bits; that is, the device can present at least three levels of identifiable asperity. From the above, we can use the asperity stimuli presented by a passive haptic interface as tools for information transmission.

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