Haptic Feedback by One-way Resisting Torque to Assist Manipulation of Control Input with a Lever

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Abstract

The operational feelings of manual control levers are important to maneuver devices that need manual operations according to user intentions. In this study, we built and tested a prototype of a manual control input lever having a single degree of freedom, which uses a magnetic particle brake in a rotational joint in place of servomotors. A one-way clutch is mounted on the rotating shaft so that the resisting torque of the magnetic particle brake is transferred to the lever unidirectionally. The drag torque is activated haptically by the appropriate actuation of the magnetic particle brake to support the manipulation. In order to assist in deciding the control input, the lever displays a resisting torque against user operations. Our system aims to reduce the burden on the operation with respect to user intentions. We examined the influence of the resisting torque by psychophysical methods. The study results enable control input devices to adapt the ability of movement and preference of the user.

Keywords: control input device, haptic feedback, magnetic particle brake, psychophysical method

1 Introduction

The motion control ability in humans has a complex relationship with the accuracy of sensory perception. The reaching motion, one of the human motion control abilities, usually has periods of acceleration and deceleration in proximity of the starting position and target position. Then, the time history of the velocity at the human hand forms a single-peaked preference. During the deceleration period, the accuracy of sensory perception increases, while the differential threshold decreases [1]. This has been shown in lifting weight experiments, where the weight changes during the lifting task [2]. In another report [3], the psychophysical method has been used to analyze the relationship between the elasticity of a virtual spring and the delay of haptical display. It has been shown that the point of subjective equality (PSE) decreases with increase in delay. It has also been reported that the visual information displaying the travel distance cannot increase the perception of elastic force. In another report, the discrimination threshold to the impedance of a control input device has been evaluated quantitatively by performing the task of tracking a periodically moving target, and equivalent sensitivity has been proved. As reported in these previous studies, the generation of sensory perception during movement is related not only to the sensory input of outside stimuli from the sensing organ but also to the information process in the locomotor system, such as the movement command.

Sensory inputs and physical capabilities are used when we maneuver some mechanism or device. The sensory inputs include visual sense, auditory sense, and haptic sense. The physical capabilities include movement of arms, fingers, and legs. Kaede *et al.* created prototypes of a two-linked lever mechanism and a handwheel device with the function of changing the feeling of manipulation, and investigated the manner of displaying the resisting torque and its effect on usability [4], [5].

In the manufacturing industry, the feel of manual handling on a workbench has been long studied to improve the efficiency of workers. Nowadays, work environment must be considered from the viewpoint of gerontology. A type of robotic arm has been utilized to assemble heavy parts easily [6]-[8]. Most of these robotic arms are equipped with a pneumatic cylinder or servomotor system in their joints, and are controlled by feedback based on position, reaction force, and other sensory information. These arm motions are said to be "active." In the service industry, which includes social service, transportation, and movement support, the applications of equipment using robotics technology are increasing [9]-[11]; so far, nursing-care robots have attracted considerable interest. The equipment that provides nursing care safely and reliably has high potential demand. For use in homes or nursing institutions, low acoustic noise and energy-saving

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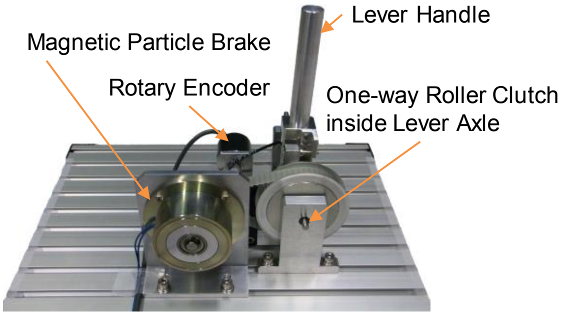
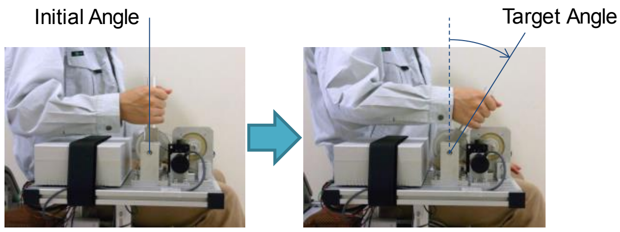


Fig. 1 Manual control lever with Magnetic Brake that is Connected by One-way Clutch Mechanism.



(a) Initial Position (b) Tilting the Lever
Fig. 2 Trial of Manipulation with Resisting torque.

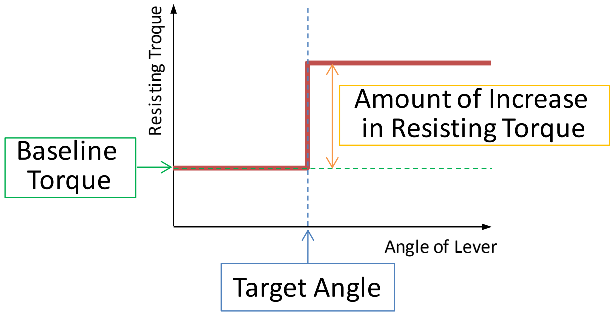


Fig. 3 Change in Resisting Torque from Baseline Torque to Step-Up Torque around the Angle of Target.

performance are also expected. We propose a passive mechanism that exploits a magnetic particle brake module, which can display resisting torque. The passive module is expected to be utilized as rehabilitation aid because it meets the requirements of safety and low acoustic noise [12]. Sekine *et al.* [13] developed a parallel link mechanism with powder clutches. Haraguchi et al. [14] developed a two-dimensional passive force display system with low voltage driving electrorheological (ER) fluid brakes. Kikuchi *et al.* [15] suggested an isokinetic exercise training and evaluation system using an ER brake.

In this study, the resisting torque is applied to an operator manipulating a lever arm, in order to help the operator decide the amount of control input. The resisting torque can be auxiliary information. Our goal is to develop a method to assist the manipulation of control input with a lever. The method matches the human mechanism of sensory perception; hence, it can reflect the intention of the user and reduce the burden for operation of personal use devices. Additionally, we discuss the application of the control input device that can adapt to the ability of movement or individual preferences. We design an experimental equipment to perform the manual control input with a lever arm, which is envisioned as an acceleration lever of an electric wheelchair or a throttle of a mobility scooter. A magnetic particle brake is connected to the one degree of freedom (DOF) control input lever, and the resisting torque and operability of this system are evaluated. The additional function of using the magnetic particle brake can assist control input passively, and satisfy the requirement of safety, reliability, low acoustic noise, and low energy consumption.

2 Design of the prototype

The operational feelings of manual control levers are important to maneuver devices that need manual operations according to user intentions. As shown in **Fig. 1**, we build an experimental system that can perform the action of manual control input with its lever. A magnetic particle brake is installed on the base frame and is connected to the joint by a timing belt. The magnetic particle brakes are sort of torque devices, and are popularly known as powder brakes. The torque is controlled by an electric circuit that varies the excitation current. It can produce a smooth braking torque through the friction between the rotor and stator. The powder brakes produce their rated torque at zero speed. This device is generally used as unwind and rewind torque control, with load cells, dancer, and tension control to maintain constant tension.

The angle of the lever is measured by the rotary encoder connected to the lever link routed over the magnetic particle brake. The angle is defined as the relative angle from the vertical position. The output pulses are counted by a microcontroller to calculate the angle and the angular velocity of the lever arm. Therefore, a manual control input device, which decides the amount of control input according to the detected lever angle, can be simulated.

The center of mass is located at the center of rotation so that the lever balances around the rotation axis, and the torque required to change the angle of the lever is not affected by the posture of the lever arm. This design aims to realize an assistive technique that teaches the operator the appropriate value of control input by the force feedback. Selector switches equipped with a detent, called snap-action or cam-action, are conventionally used as a force feedback technique to assist in the operation. This is a useful function in case the options of appropriate control values are known during the design phase. However, a new mechanism is needed if driving a moving vehicle, during which the position of displaying click feeling should change actively to adapt to the immediate environment.

Additionally, a one-way roller clutch is mounted on the rotating shaft so that the resisting torque of the magnetic particle brake is transferred to the lever unidirectionally. In case of driving an electric wheelchair, the value of the control input is the target velocity, which is determined on the basis of the control lever’s angle. To ensure safe operation, the resisting torque is activated in the direction of the target value increase, and only the restore torque is activated in the direction of the target value decrease.

It is easy to design an appropriate relationship between the lever’s position and the displaying resisting torque with this mechanism, and then, the technique of resisting torque feedback can be deployed in the area in which operational assistance is needed.

3 Experiments

In this study, we conduct psychophysical tests to determine the reaction of subjects against a resisting torque with several patterns related to lever operation. Especially, we elucidate whether a subject can distinguish the change in the amount of resisting torque and halt the operation when the resisting torque increases. The experimental procedure is as follows:

1) A subject grips the lever handle that is in the initial position, as shown in **Fig. 2 (a)**, and starts tilting the lever forward.
2) The resisting torque against the lever operation increases as shown in **Fig. 3** when the angle of the lever reaches the target angle, which is predetermined.
3) The subject halts the operation, as shown in **Fig. 2 (b)**, when he/she perceives the change in the resisting torque, and informs the experimenter of detecting this change. In contrast, the experimenter records "undetectable" when the subject cannot perceive the change in the resisting torque and tilts the lever up to the mechanical limitation.
4) The lever's angle is recorded when the subject perceives the change in the resisting torque and halts the operation.
5) The lever's angular velocity is recorded just after the resisting torque increases. The subject is supposedly in operation at the time.

Here, we target the operation of tilting a lever arm forward, but not the return motion.

4 Effect of changes in the target angles on the discrimination threshold

The amount of rising up torques that the subject can detect while operating the lever is measured using the method of adjustment with ascending series. A control knob is set up in front of the controller box. The subject adjusts the knob to increase the rising up torque during procedure 2 (see previous Experimental section), and informs the minimum perceivable torque setting to the experimenter. We prepare three target angles of 0.5236 rad (30°), 0.7854 rad (45°), and 1.0472 rad (60°) as target angles at which the resisting torque increases. These target angles include the range of motion of the general operation lever. The change in the resisting torque is perceived as the difference between the baseline torque and the step-up torque. The baseline torque changes to 0.04, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 2.0, 3.0, and 4.0 Nm. The subjects in this experiment were three healthy men of 20–30 years of age. Averages and standard deviations of the minimum noticeable increases in the resisting torques are shown in **Fig. 4**. The effect of change in the target angles on the discrimination threshold is small and the minimum noticeable increase in the resisting torque varies among different individuals.

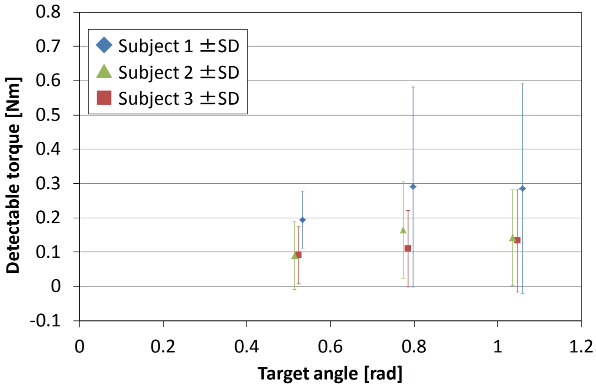


Fig. 4 Minimum Noticeable Increase in the Resisting Torque at the Three Target Angles.

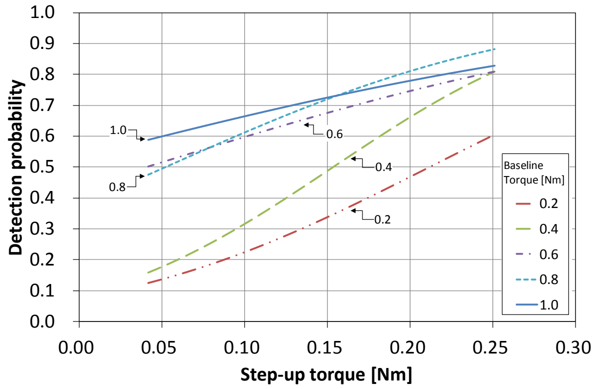


Fig. 5 Fitting Curves of the Detection Probabilities (Target Angle: 30°).

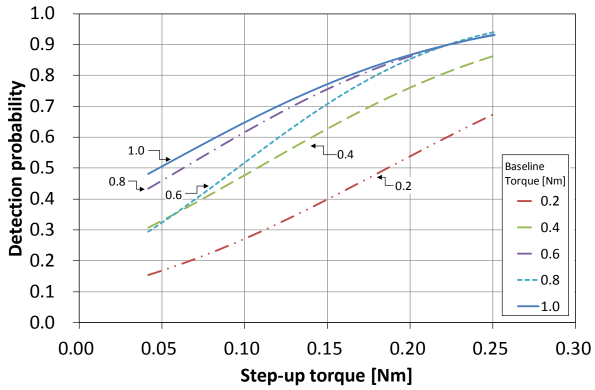


Fig. 6 Fitting Curves of the Detection Probabilities (Target Angle: 45°).

5 Effect of changes in the baseline resisting torques on the discrimination threshold

The relationship between the increase in the resisting torque and detection probability is measured using the constant method at different baseline torque conditions. As described in section 4, changing the target angle has little effect on the discrimination threshold of the sensory perception. We display two target angles (0.5236 rad [30°] and 0.7854 rad [45°]) to prevent errors caused by habituation or expectation. The baselines of the resisting torque are set to 0.2, 0.4, 0.6, 0.8, and 1.0 Nm, which is approximately the threshold obtained in the previous experiment. The amount of increase in the resisting torque is set to 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.10, 0.11, 0.12, 0.13, 0.14, 0.15, 0.16, 0.17, 0.18, 0.19, 0.20, 0.21, 0.22, 0.23, 0.24, and 0.25 Nm. All combinations of the 220 trial conditions are randomly displayed to the subjects. The subjects in this experiment were five healthy men of 20–30 years of age. The fitting curves of the detection probabilities of changes in the resisting torques are estimated on the basis of a cumulative normal distribution. The fitting curves categorized by the target angles and the processed statistics are shown in **Figs. 5 and 6**, respectively. Accordingly, all the obtained data have high detection probabilities with increasing amounts of rising up torque. It is intuitively understandable that the larger the difference between the baseline torque and step-up torque becomes, the easier it is to discriminate the change in the resisting torque with sensory perception. Additionally, the detection probability increases with increasing baseline torque under the condition of the same amount of increase in the resisting torque. Differences in the target angles do not influence the detection probability.

6 Effect of changes in the angular velocity of lever operation on the discrimination threshold

The discrimination threshold of human sensory perception is well represented by the Weber–Fechner's law, which describes the relationship between the magnitude of a physical stimulus and the intensity. The relationship between stimulus and perception is logarithmic. Then, if the mass is doubled, the threshold is also doubled. This law is useful in case of stimulus of weight and brightness. However, as per our experimental condition, the amount of increase in the resisting torque to be discriminated, which is the differential change in perception, is small when the baseline torque, which is the stimulus at the instant, increases. Therefore, the Weber–Fechner's law cannot explain our experimental results.

From another standpoint, there is a report that analyzes the relationship between the ability of sensory perception for impedance and the discrimination threshold of the impedance in the system of human–machine interaction [16]. A linear robot with one DOF is manipulated by a trial subject who receives feedback from the visual and haptic senses to increase the human ability of perception for the impedance. In that study, it was reported that the value of the discrimination threshold increases proportionally and the dispersion of the accuracy decreases under some circumstances, such as multiple impedance perception and large robot viscosity. In other words, the increase in the displaying impedance causes the increase in the differential limen. Our study uses different the experimental conditions in that the trial operation is the rotational motion of a lever arm and the subjects do not receive visual feedback; however, the results in this paper suggest that the velocity of the motion affects the ability of sensory perception.

The relationship between the baseline torque and the angular velocity of the lever at the moment of reaching the target angles is shown in **Fig. 7**. Averages and standard deviations are calculated using all experimental conditions of all subjects. Multiple comparisons by using the Tukey–Kramer's method are performed for the combinations of baseline torques, and the angular velocity at the moment of reaching the target differs significantly for the combinations of 0.2–0.6, 0.2–0.8, 0.2–1.0, and 0.4–1.0 Nm at the 5% significance level.

These results suggest that increasing the amount of baseline torque increases the sensory perception because of the decrease in the angular velocity of the lever operation and increase in the ability of discrimination.

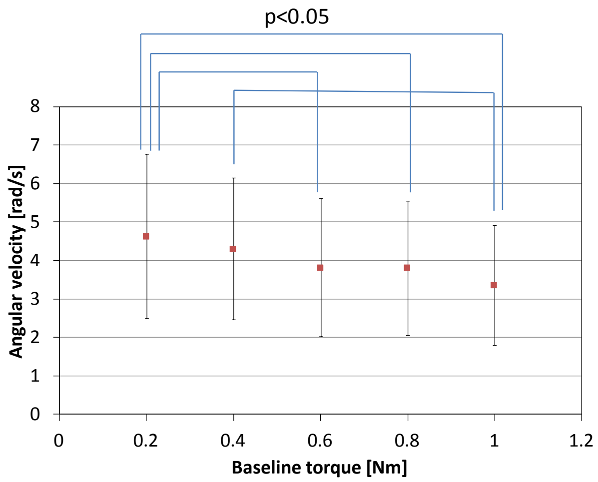


Fig. 7 Angular Velocity of Lever at the Moment of Reaching to Target Angles

7 Conclusions

In this study, we investigated the relationship between the sensory perception of a person who is manipulating a lever arm and the amount of resisting torque against the manipulation to examine the effect of haptic feedback on the operator. The resisting torque feedback can be used as auxiliary information to determine the amount of operator input. We set up a prototype of an operational input device that consists of a lever arm with one DOF and a magnetic particle brake connected by a one-way clutch. The psychophysical method has been used to analyze the sensory perception while manipulating an operational lever device. The conclusions of this study are summarized as follows:

1) The effect of changes in the target angles on the discrimination threshold is small, and the minimum noticeable increase in the resisting torque varies among different individuals.
2) The larger the difference between the baseline torque and step-up torque becomes, the easier it is to discriminate the change in the resisting torque with sensory perception. Moreover, the detection probability increases with increasing baseline torque under the condition of the same amount of increase in the resisting torque.

3) The increase in the amount of baseline torque causes the increase in the sensory perception because of the decrease in the angular velocity of the lever operation and increase in the ability of discrimination.

These findings will contribute to improving operational input devices having the function to negotiate with the mechanism of human sensory perception.

References

[1] Masayui Hara, Takeo Yamagishi, Naoya Ashitaka, Jian Huang and Tetsuro Yabuta, "Examination of Human Weight Perception Using a Force Display Device", Proceedings of the 2007 JSME Conference on Robotics and Mechatronics, (2007), 1A2-F03.

[2] Hitoshi Ohnishi, Daisaku Hayashi, Naoto Nakamura and Kaname Mochizuki, "Effect of Delay of Feedback Force and Visual Information on Perception of Elastic Force", The institute of electronics, information and communication engineers, Technical Report, (2007), pp. 37-41.

[3] Keiichi Onish, Youngwoo Kim, Goro Obinata and Kazunori Hase, "Quantitative Evaluation of Impedance Perception Characteristics of Humans in the Man-Machine Interface", Springer, Journal of Mechanical Science and Technology, Vol. 27, Issue 5, (2013), pp. 1341-1350.

[4] Kazunori Kaede and Keiichi Watanuki, "Generation of Tactile Feeling through the Frictional Torque of Magnetic Particle Brakes", Trans. of JSME, Vol. 78, No. 796, (2012), pp. 3855-3865.

[5] Kazunori Kaede and Keiichi Watanuki, "Operational Assistance of Manual Control Input by Displaying One-Way Resistance Torque", Proceedings of The 5th International Conference on Manufacturing, Machine Design and Tribology, (2013), PB-28.

[6] Yoji Yamada, Hitoshi Konisu, Tetsuya Morizono and Yoji Uemura, "Proposal of Skill-Assist for Mounting Operations in Automobile Assembly Process", Trans. of JSME, Vol. 68, No. 666, (2002), pp.509-516.

[7] Hitoshi Konosu, Isamu Araki and Yoji Yamada, "Practical Development of Skill-Assist", Journal of the Robotics Society of Japan, Vol. 22, No. 4, (2004), pp. 508-514.

[8] Yu Ogura, Masakazu Fujii, Kazuyuki Nishijima, Hiroki Murakami and Mitsuharu Sonehara, "Applicability of Hand-Guiding Robot for Assembly-Line Work", Proceedings of the 2011 JSME Conference on Robotics and Mechatronics, (2011), 2A1-B07.

[9] Yoshihiro Nakabo, Suwoong Lee and Yoji Yamada, "Vision and Force Sensor Systems for the Robot that Safely Coexists with Human", The Journal of Reliability Engineering Association of Japan, Vol. 29, No. 5, (2007), pp. 301-309.

[10] Yoshiteru Terashi, Hiromitsu Kobayashi, Ryuji Katamoto, Kaoru Fujiie and Yoshito Ehara, "Feeling of Switches for Assistive Technology", Proceedings of the Welfare Engineering Symposium 2005, (2005), pp.189-190.

[11] Takayuki Saito, Toyohiko Hayashi, Yasuo Nakamura and Naoki Tondokoro, "A Computer-Aided System for Selecting Optimum Operating Switches for Subject's Remaining Physical Functions", The institute of electronics, information and communication engineers, Technical Report, Vol. 103, No. 114, (2003), pp. 49-54.

[12] Junji Furusho, Ken'ichi Koyanagi, Jiro Kataoka, Ushio Ryu, Akio Inoue and Shigekazu Takenaka, "Development of 3-D Rehabilitation System for Upper Limb -1st Report: Development of Mechanism including ER Actuators and Whole System-", Journal of the Robotics Society of Japan, Vol. 23, No. 5, (2005), pp. 629-636.

[13] Toshiaki Sekine, Toshio Nagura and Kiyoshi Komoriya, "Method of Forceindicating with Powder Clutch", Proceedings of the Japan Society of Mechanical Engineers Kanto-Block Conference, (2001), pp. 243-244.

[14] Makoto Haraguchi, Hiroshi Kobayashi, Akio Inoue and Junji Furusho, "A Development of 2-D Force Display System with Redundant Low-voltage Driving ER Fluid Brakes", Journal of the Society of Rheology, Japan, Vol. 38, No. 2, pp. 99-105.

[15] Takehito Kikuchi, Junji Furusho and Kunihiko Oda, "Isokinetic Exercise Training and Evaluation System Aimed High Velocity Training (The system using ER brake), Transactions of the Japan Society of Mechanical Engineers, C, Vol. 69, No. 686, (2003), pp. 2723-2728.

[16] Toshio Tsuji, Tomoyuki Shimazaki and Makoto Kaneko, "Analysis of Human Perception Ability for Robot Impedance", Journal of the Robotics Society of Japan, Vol. 20, No. 2, (2002), pp. 180-186.

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