Preliminary Evaluation of a 3-DoF Magnetic Haptic Display for Contactless Force Presentation*

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I. Introduction

Haptic displays can be divided into two types, grounded and ungrounded types [1], depending on how the device is mounted. In the former, physical connections such as robotic arms or wires inhibit user movement and visual presentation, while in the latter, accurate force presentation is difficult due to unpredictable factors such as individual differences in illusory force perception. As an intermediate method that can overcome the shortcomings of both methods, haptic displays using magnetic force have been developed. In these devices, the magnetic field generated by grounded electromagnets is used to actuate the handheld part in a contactless manner [2], [3]. However, magnetic haptic displays that are comparable to existing grounded displays in terms of freedom of hand movement and degrees of freedom (DoF) of force have not yet been developed. In this study, we propose a haptic display that can display forces in 3-DoF without restricting the user's movement by using a set of electromagnets with a large opening and a permanent magnet that can be rotated in any direction. We also conduct experiments to verify the accuracy of the force that can be presented.

II. Proposed Device

The proposed haptic display consists of a grounded part and a handheld part. The grounded part (Fig. 1, left) consists of three pairs of square Maxwell coils [4] (maximum length of one side is 242 mm, maximum spacing is 210 mm), which can generate a magnetic field with a nearly constant gradient in any direction. The handheld part (Fig. 1, right) consists of a cylindrical neodymium magnet, 20 mm in diameter and 20 mm long, mounted on a gimbal mechanism and surrounded by three orthogonal coils that allow the magnet to be oriented in any direction. Force is presented by creating a magnetic field gradient proportional to the target force with the Maxwell coils and simultaneously rotating the magnet in the handheld part in the same direction as the force. This maximizes the force without creating unnecessary torque.

III. Evaluation

To evaluate the force linearity, we commanded the force in 11 steps in the x-axis and measured the actual force with a 6-DoF force plate. The measured forces are shown in Fig. 2, and a very high linearity was obtained with a correlation coefficient of $R = 0.9997$ in the x-axis. In addition, the maximum force was about 0.6 N. The maximum torque, which should ideally be zero, was approximately 0.02 Nm.

To evaluate the directional accuracy of the force, force commands of the same magnitude were applied in different directions on the x-z plane, and the angular error between the commanded and measured values of the force vector was calculated. However, very large errors (up to 175 degrees) were observed, indicating that the permanent magnet did not rotate according to the command. Therefore, in the future, the rotation of the magnet must be accurately controlled by feedback control.

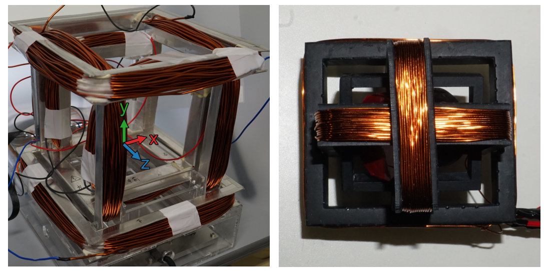

Fig. 1. The proposed device. Left: The grounded part and coordinate axes. Right: Internal structure of the handheld part.

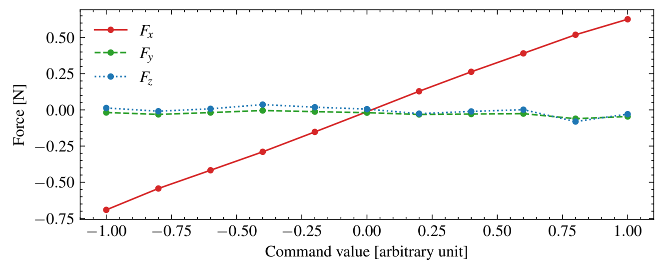

Fig. 2. Relationship between commanded and measured force.

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