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# A 2-DOF MR actuator joystick for virtual reality applications

W.H. Li*, B. Liu, P.B. Kosasih, X.Z. Zhang

*School of Mechanical, Materials and Mechatronic Engineering, University of Wollongong, Wollongong, Norfhfields Avenue, NSW 2522, Australia*

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**Abstract**

The paper presents the design and development of a magnetorheological (MR) fluid-based haptic system and studies its applications in virtual reality. The developed system consists of three main parts: MR joystick, control and display hardware, and software. The MR joystick was constructed of two disc-shaped MR actuators positioned perpendicularly with a gimbal structure, which transfers the movement of the joystick handle into two actuator rotary movements. Therefore, operators can feel the resisting force generated by the two actuators. The dimensions of the actuators were optimized using finite element analysis. The steady-state performance of the actuators was measured and a subhysteresis model was proposed to effectively predict the actuator performance. The kinetics of the joystick in terms of working space and resistance was discussed. The applications of the MR joystick in virtual reality were demonstrated by using four typical 2D and 3D interface examples designed with LabVIEW software package.


*Keywords:* Haptic device; Virtual reality; MR actuator; Joystick; Subhysteresis; Interface

## 1. Introduction

Magnetorheological (MR) fluids, and electrorheological (ER) fluids, exhibit unusual characteristics in that their rheological properties can be continuously and reversibly changed within milliseconds by solely applying or removing a magnetic or electric field. This feature can be applied to a wide range of technologies requiring damping or resistive force generation [1]. For example, to address the need for interaction with remote and virtual worlds, haptic devices based on ER or MR technology would be designed to bridge the gap between the real and virtual world. Haptic systems are implemented for study of the coupling of the human sense through “touch” and a computer-generated environment. A common example of such a system is in computer games, where the action on a video display and the movement of a joystick or steering the device are coordinated with physical force imparted to the operator’s hand, through the joystick or steering device, to provide a simulated “feel” for events happening on the display.

To date, haptic system is a less-developed modality for interacting with virtual worlds compared with visual and auditory feedback. Most of these devices work on the principle of applying force or moment equal or proportional to a force or moment generated in the virtual environment through the use of actuators and motors. They have the common disadvantages of being heavy, costly and present great difficulties in emulating the feeling of virtual stiffness [2].

To overcome the drawbacks of conventional systems, a few groups attempted to develop ER fluid and MR fluid-based haptic devices. Kenaley and Cutkosky [3] did pioneer work on the use of ER fluids for tactile sensing in robotic fingers. Taylor et al. [4] developed and tested experimentally a 5 × 5 ER fluid tactile array. Kaczmarek et al. [5] proposed a tactile display that was used to produce tactile sensing on the skin of the operators. A similar tactile device was designed by Kajimoto et al. [6], where ER fluid in the tactile array could work in either squeeze mode or shear mode. ER fluids were also developed to force-feedback systems to simply and enhance the human–device interfaces. Furusho and Sakaguchi [7] developed an ER fluid-based planar force-feedback manipulator system, actuated by low-inertial motors equipped with an ER clutch, for virtual reality applications. Bose and Berkemeier [8] developed an ER fluid-based haptic joystick. The joystick is composed of a ball and socket

* Corresponding author. Tel.: +61 2 42213490; fax: +61 2 42213101.
*E-mail address:* weihuali@uow.edu.au (W.H. Li).

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joint where ER fluid was placed in the space between the ball and the socket. The operator feels a resistive force to his/her motion resulting from the controlled viscosity of the ER fluids. Mavroidis and his group at Northeastern University in USA developed an ER-fluid-based haptic system called MEMICA [9]. The MEMICA system was intended to provide human operators with an intuitive and interactive feeling of the stiffness and forces in remote or virtual sites in support of space, medical, and virtual reality robots performing dexterous manipulation operations. Recently, their group developed ER fluid resistive actuators for haptic vehicular instrument control [10]. This device could resist human operator forces in a controlled and tunable fashion.

Similarly, MR fluid-based haptic displays and haptic interfaces have been investigated by some researchers. Carlson developed a prototype of portable hand and wrist rehabilitation MR device [2]. Bicchi et al. used MR fluid to construct a haptic display to replicate perceived biological tissue compliance [11]. Liu et al. [12] developed a single cell MR fluid-based tactile display to simulate the action of a human finger's touch. As the yield stress of MR fluids is much higher than that of ER fluids, MR fluid-based force-feedback system would provide much larger resistive ranges compared with ER device. Furusho's group [13] also developed a MR haptic display employed two groups of MR actuators to simulate virtual forces in two-dimensions, respectively. There are two MR actuators and a DC servomotor in each group, and the mechanical structure combines forces from the two groups to execute the simulation in a two-dimensional area. The maximum output torque is 10 Nm in each dimension, much larger than that of ER joystick with only 0.5 Nm [7]. An MR haptic glove was developed by adopting several compact MR disc-shaped actuators to generate torque on the back of each finger [14]. These actuators can work together through a link structure to simulate the virtual force, which is strong enough for large force applications.

This project aims to develop a MR haptic device for virtual reality applications, such as virtual training. This paper is organized as follows. The system description is firstly outlined. Then the optimal design, analysis, testing and modeling a MR actuator will de detailed. The joystick kinematics in terms of motion analysis and compensator will be discussed. The system implementation and interface design will be addressed.

## 2. System overview

This system is a combination of virtual instrument techniques and special physical property of MR fluids. The developed system consists of four main components: MRF haptic joystick, server computer, data acquisition (DAQ) board and power amplifier. The schematic diagram of the system is shown in Fig. 1.

The central force performance part in this system is the MR haptic joystick, which ensures the user to feel different resistant force according to the virtual environment and sends the position for the handle to the computer by the DAQ board. The computer performs as the control and the display unit in this system. The user designs a virtual environment by 2D or 3D picture modeling and control tool in the computer. Based on the 2D or 3D images the computer generates control signals, which

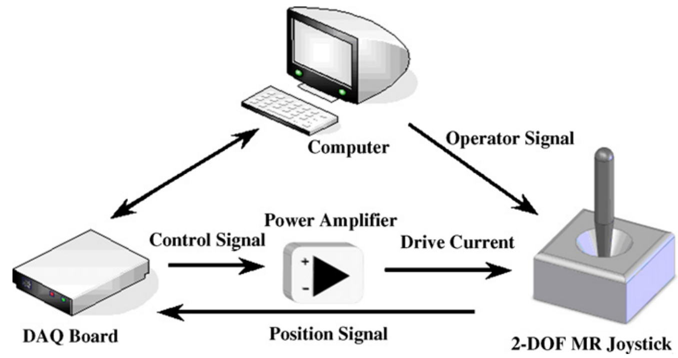


Fig. 1. Schematic representation of the 2-DOF MR haptic system.

correspond to the virtual environment and the position of the joystick handle detected by the position sensors. Meanwhile, the computer shows the updated picture to the uses. The DAQ board is the information exchange platform between the computer and the joystick. It transfers the position signal, detected by the position sensor on the joystick, to the computer for force calculation and sends the force control signal to the amplifier to drive the MR joystick. The small control voltage signal can be amplified up to 2.2 A current signal by the power amplifier, since the computer and the DAQ board cannot provide so strong current to drive the joystick directly. Consequently the operator can feel the different resistant forces when the operator moves the cursor, controlled by the joystick, through the image shown on the screen of the computer.

## 3. Design and development of MR actuators

The side view of the position-feedback MR actuator is shown in Fig. 2. When the disc rotates in the MR fluid contained in the mild steel case, the resistant force generates between the disc surface and the inner surface of the case. The resistant force is very small in the absence of a magnetic field, because the shear stress of MR fluid is very small without magnetic field. The force increases steadily with the increase of the intensity of the magnetic field.

### *3.1. Static analysis of disc-shaped MR actuator*

The torque transmissibility of the MR actuator depends largely on the dynamic yield stress and the viscosity of the MR fluid [15]. Therefore, it is crucial to understand these MR fluid

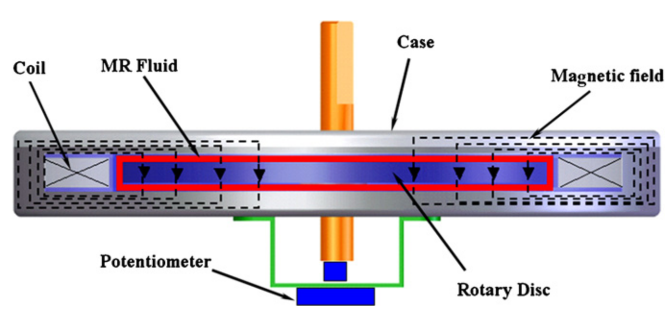


Fig. 2. Position feedback MR actuator.