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Haptic joystick with hybrid actuator using air muscles and spherical MR-brake

Doruk Senkal, Hakan Gurocak *

School of Engineering and Computer Science, Washington State University, 14204 NE Salmon Creek Ave., Vancouver, WA 98686, USA

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ABSTRACT

In this research, a new 2-DOF hybrid actuator concept is explored as a powerful and compact alternative to conventional haptic actuators. The actuator combines a spherical MR-brake and three air muscles and is integrated into a joystick that can apply forces in two degrees-of-freedom. The air muscles are used to create high active forces in a compact volume and the brake compensates for the "spongy" feeling associated with air muscles. To decrease the overall size of the system an inertial measurement unit has been implemented as a position measurement solution. As high as 16 N of total force output could be achieved at the tip of the joystick. Also, up to 16 times improvement in the stable virtual wall stiffness was obtained when the MR-brake was used to compensate for force errors. Experiments with an impedance-based haptic controller with force-feedback gave satisfactory wall following performance. This device can be employed in applications including computer games, military or medical training applications, rehabilitation and in teleoperation of equipment where high force feedback in 2-DOF in a compact work volume may be desirable while interacting with rigid or elastic virtual objects.

1. Introduction

The most common actuation method for haptic devices is electric motors. This is mainly due to their well documented advantages [1,2] including relatively low-cost, high positional and velocity accuracy, quite actuation and well-documented means of control. In haptics these advantages usually translate to high bandwidth and resolution, low backlash and friction. However, electric motors suffer from low torque-to-weight ratio which severely limits the peak force of lightweight haptic devices. This becomes especially important in applications such as wearable haptics [3] and exoskeletons [4] where available space and/or total mass of the system are limited. The most commonly used work-around for this problem is to place the actuators in a remote location and use transmission mechanisms such as gears, cables/capstones, to transfer the forces to the user. This approach limits the mobility of these devices. Hence a high torque, transparent actuator for haptics is highly desirable.

Many authors have researched alternative actuation schemes for haptics applications. Some of these actuators are magnetorheological (MR) [5,6] and electrorheological (ER) [7,8] brakes, particle brakes [9], air-jets [10,11], eddy-current brakes [12] and air muscle actuators [13–15]. A qualitative comparison of these actuators and electric motors can be found in (Table 1). As it can be seen in Table 1, all of these actuators excel at certain tasks, but no single actuator is fully capable of meeting the requirements of haptic applications [16]. In general, haptic applications require high power, compact and linear actuators. Current actuators cannot satisfy all of these requirements. For that reason "actuator problem in haptics" remains largely unanswered.

In order to tackle this problem, previously we built compact and powerful MR-brake actuators [5,17,18]. These actuators were based on a new concept called "serpentine flux path", where the magnetic flux was weaved through the MR fluid gap using magnetically conductive and non-conductive elements. This method allowed us to increase the torque output of the actuator without increasing its size. Using the same concept, we then designed a multi degree of freedom (DOF) spherical MR-brake. This spherical MR-brake, first of its kind, allowed motion in 3-DOF. When activated, it was able to lock all three DOF at once [6]. Virtual wall collision in haptics represents collision of the tracker with the surface of a virtual object. It is used as a way to assess the ability of a haptic device to render virtual objects. The spherical MR-brake had very high torque output hence was able to provide very rigid virtual wall collisions. Therefore, compared to the devices using motors, we could significantly improve the perceived rigidity of a virtual wall (or object) while keeping the size of the actuator small.

However, due to its passive nature, the spherical MR-brake had limitations. It could only simulate rigid virtual objects. It could not add energy to the system or provide a restoring force (as in a compressed spring) to simulate elastic virtual objects. An interface with both capabilities can find many applications including computer games, military or medical training applications, rehabilitation and in teleoperation of equipment.

* Corresponding author. Tel.: +1 360 546 9637; fax: +1 360 546 9438.
E-mail address: hgurocak@vancouver.wsu.edu (H. Gurocak).

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