Smart mouse: 5-DOF haptic hand master using magneto-rheological fluid actuators

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Smart Mouse: 5-DOF Haptic Hand Master Using Magneto-Rheological Fluid Actuators

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Abstract. This paper is concerned with a haptic hand master intended to display force feedback at the fingertip of the human user. The haptic hand master, named ‘Smart Mouse’ has two significant differences from previous other hand masters: actuators and structure. Five passive actuators featured with magneto-rheological fluid are used to ensure the interface safety and the control stability. In order to eliminate the unnecessary reaction force and reduce muscular fatigue during operating, the mouse-like structure is adapted. Also, two assumptions are proposed for the simplicity of its kinematics and manufacturing: one is that the fingertips lies on a plane during grasping the objects, and the other is that the equilibrium point of the fingertip reaction forces is in the object. Due to these characteristics, the human hand operating the smart mouse has the kinematic configuration similar to a 5-DOF parallel manipulator.

1. Introduction

Human hands enable dexterous manipulations such as handling tools, fabrications, and drawings. Especially, multi-fingered manipulations are highly adaptable to extreme environments including nuclear reactors, underwater or space. Therefore, haptic devices with multi-finger inputs are attracting much attention in these days. Generally, such haptic devices are named the ‘haptic hand master’. For past decade, several haptic hand masters have been developed and now in practice [1-6]. The conventional haptic hand masters can be generally divided into two categories: the ground-based type and the body-based type. Ground type devices are fixed to its environment such as desk, ceiling or wall. The weight of the devices can be compensated. However, because they are mainly using a pen or a ball, it is difficult to develop devices with multi-finger inputs. On the other hand, the body-based type haptic devices have their ground on the operator’s body. Since the shape of the device is very much like a glove, the operator can manipulate it intuitively and portably. However, the operator should bear the weight of device, leading to physical fatigue in long-period use. Therefore, the authors have considered that its mobility on the plane and implementability of the multi-fingered inputs make the mouse-like shape device more attractive. According to the locations of the actuators, the haptic hand masters can be again classified into two categories: the exoskeleton type and the endoskeleton type. Most of the existing exoskeleton type devices provide forces onto the fingertips by pulling them backwards, either having the actuators integrated in the exoskeleton or remotely located. On the other hand, the actuators in the endoskeleton
type devices provide forces onto the fingertips by pushing or resisting against them. Unfortunately, both types do not feel free from unrealistic constraint forces that disturb the operator. For the selected concept in this paper, its actuators are not placed on the human body such as the palm of the hand or the wrist, but on the mouse-like haptic device. This consideration can make them independently attached to the corresponding fingers without any constrained forces. In the conventional haptic hand masters, force feedback mechanisms can be divided into two categories: the active type and the passive type. The active type displays force feedback using actuators such as electromagnetic motors or hydraulic/pneumatic cylinders. However, this type gives potential danger to the operator because the actuators can move independently regardless of the operator’s intentions. On the other hand, brakes and crutches are mainly applied for the passive type. Actuators in this category are not activated until the operator manipulates the devices. Therefore, it is possible to display a large force feedback without danger. Obviously, force patterns that can be displayed by the passive force mechanism are limited. Nevertheless, this type seems to be more promising for the proposed haptic hand master, in the viewpoints of the interface safety and the haptic stability. Consequently, this work proposes the new type device, which is called the ‘Smart Mouse’ (figure 1). The proposed device has the following characteristics. (i) The mouse-like shape for mobility and portability. (ii) The endoskeleton-type attachment of the actuators for haptic fidelity. (iii) The passive force feedback for interface safety and haptic stability.

2. Mechanisms of the Smart Mouse
In order to develop the mechanism of the smart mouse, the following anatomical features of the human hand in grasping a real object are considered; (i) Because fingertips are mainly used for the dexterous tasks, only the positions and reaction forces of each fingertip are required to be measured. (ii) Obviously, humans have a certain functional position. The most appropriate position for grasping or manipulating of the human hand can be considered in the case that all of the fingertips are placed on a certain plane. (iii) The reaction forces from the object act against the finger’s flexion, which is generated by the muscles and tendons in the hand and the forearm. Here, it can be sensibly assumed that these reaction forces are normal to the contact surface. (iv) Statically stable grasping can be achieved only when the equilibrium point of the reaction forces is within the object, but not on the body such as the palm of the hand or the wrist. In these anatomical viewpoints, the kinematic model of the smart mouse is proposed as shown in figure 2. Due to these characteristics, the human hand in operating the smart mouse has the kinematic configuration similar to a 5-dof spatial parallel manipulator. In order words, it can be considered that the plane on which the actuators are placed is the base platform of the manipulator, the palm of the hand is the moving platform, and each of the
fingers is the connecting limb with four passive revolute joint. Here, the actuators play a role to control the position of the 1-dof revolute joint on the plane as well as to provide the reaction force to the fingertip. For 5-dof spatial parallel manipulator with five actuators, the position/orientation of the moving platform and the positions of all the passive joints can be analytically determined from the given position of all the actuator. Based on this fact, the spatial configuration of the human hand in operating the smart mouse can be obtained only by using five actuators.

3. Structure of the Smart Mouse

3.1. Actuator: Miniature MR Fluid Actuator

For the passive force feedback of the smart mouse, the magneto-rheological (MR) fluid actuator is adopted. MR fluid is a non-colloidal solution which is composed of ferromagnetic particles with micrometers in diameter dispersed in a nonconductive carrier fluid. The MR fluid has the characteristic that their rheological properties are continuously and reversely changed within several milliseconds solely by applying or removing external magnetic fields. Due to this feature, devices using the MR fluid are simple in construction, high in power and low in inertia, compared to conventional actuation methods. Especially, MR actuators can provide much safety in equipment interacted directly with human, due to its inherent stabilizing effect as a passive device. The MR fluid actuator proposed in this work and its schematic configuration are shown in figure 3. This actuator is designed with the mechanic and electromagnetic viewpoints. This is composed with a cylinder, two piston rods and a piston head. The ferromagnetic material for the cylinder and piston head is mild steel, SS41. The piston rods are made with stainless steel which does not influenced by magnetic field. The MR fluid is MRF-132AD composed by LORD Corporation. When the piston head moves, the MR fluid is moved through the annual gap between the cylinder and the piston head. When an external current is supplied to the electromagnetic coil, the corresponding magnetic field is applied to the MR fluid in the gap. Then, the dynamic yield stress of the MR fluid is changed depending on the magnetic field intensity, and the resultant output force is activated in the opposite direction to the motion of the piston head.
Therefore, the reaction force of the MR fluid actuator can be continuously and reversely controlled by adjusting the applied coil current. The full stroke of the actuator is 20mm and its weight is about 52g. The further specifications and design parameters are shown in figure 4.

3.2. Sensor
As shown in figure 3, the displacement sensor for the actuator consists of a sensor casing, a Hall-effect sensor, and a permanent magnet. When the permanent magnet attached to one end of the piston rod is close to the Hall-effect sensor, the magnetic flux density between them is increased. Therefore, the displacement of the piston head can be measured with Hall-effect sensor which outputs the voltage corresponding to the magnetic flux density. The sensor case is made of aluminum which does not make the magnetic field disturbed. In a preliminary experiment, it was observed that the output voltage of the Hall-effect sensor is nearly linear to the displacement of the piston head. For this consideration, the actuators are installed on the base platform with the revolute joint. In order to obtain all positions of the finger joints from the actuator displacements, the rotational positions of the actuators are required to be known. Therefore, the revolute joint for the actuator is connected with the rotary potentiometer which can output the maximum voltage of 5V with respect to the maximum rotational angle of 270 degree. For measuring the reactive force applied to the fingertip and achieving the feedback loop in the force control, the film-type force sensor (Flexiforce®) is installed on the other end of the piston rod. This sensor is characterized by its electrostatic capacity depending on the applied pressure.

3.3. Body
Figure 5 shows the CAD drawing of the proposed device. In order to avoid the mechanical interference between the actuators during rotating, adjacent actuators are installed on the different layer to each other, and therefore the device has three layers. However, the actuator on lower layers has an extension rod in such a way that all fingertips can be placed on the top layer. Considering that the direction of the reactive force for the thumb is mostly opposite or perpendicular to other four fingers during grasping, the rotational joint of the thumb actuator is positioned at the opposite side to the human hand for its functional position. Instead, the structures of the four fingers other than the thumb are almost the same as the human hand, and are distributed parallel to each other. At the lowest part, a real computer mouse is adopted to provide the ground position of the smart mouse in the virtual environment.

4. Performance Evaluations

4.1. MR Actuator
An experimental system was constructed for the performance evaluation of the MR fluid actuator. A motor-cam system operates the actuator, and its reaction force and displacement are measured with the load cell and the laser displacement sensor, respectively. For the static characteristic, the coil current at is applied a specified level and MR fluid actuator is oscillated in a sinusoidal waveform. Figure 6 shows that the reaction force of the proposed MR fluid actuator can be effectively controlled with the coil current.
Considering that general human finger generates 15~20N, the MR fluid actuator (the maximum output of 26N at 3A) is applicable to the smart mouse. Figure 7 shows the output force histories of the MR fluid actuator with respect to the step input current of 3A. As the actuator is compressed by the motor-cam system (1rpm), the current is input. In general, actuators using MR fluid display a dynamic behavior similar to the first-order linear system where the time constant is defined as the time required for the output to reach 63.2% of its saturated value after applying the input. Based on this fact, the time constant of the proposed MR fluid actuator is found by about 42.8msec. Considering that most of the commercial available MR fluid actuator’s time constant is about 50msec, it can be seen that the proposed MR fluid actuator has good response characteristic. [7] Therefore, the applicability of the proposed actuator to smart mouse is verified.

4.2. Interface Environment
In order to evaluate the haptic performance of the smart mouse, 2D virtual environment is constructed under Visual C++ environment. Figure 8 shows the human hand in manipulating the smart glove interacted with the virtual environment, and figure 9 shows the virtual environment consisting of the simply made virtual hand and the virtual object with three different shapes (circle, triangle or quadrangle) and sizes (10, 12 or 15 cm in enveloped diameter) which is selectable on demands. Even though the spatial kinematics of the smart mouse can be actually determined, its top-viewed configuration is reflected on the virtual hand for the convenience of the implementation. The interaction of the smart mouse with the virtual hand on computer is achieved by using the digital signal processor with five DA channels for controlling the reactive force of the actuators and fifteen AD channels for measuring the Hall-effect sensors, the rotary potentiometers and the force sensors. Therefore, the human user can move the virtual object as well as perceive the touch sensation by manipulating the smart mouse. For further interaction with the virtual environment, the human user can use the visual information displayed at the left side of the viewer, such as the position of the smart mouse, the actuator displacements and the reaction forces in real time. From several subjects volunteering for evaluating the haptic performance, it is drawn that the smart mouse can reflect the motion of the human hand and display the voluminous feeling and touch sensation quite effectively.

5. Conclusion
The haptic hand master, called ‘Smart Mouse’ has two significant differences from the previous haptic hand masters: actuators and structure. Five passive actuators featured with magneto-rheological fluid
are used to ensure the interface safety and the control stability. In order to eliminate the unnecessary reaction force and reduce muscular fatigue while operating, the mouse-like structure is adapted. Also, two assumptions are employed for the simplicity of the kinematics and manufacturing: one is that the fingertips lies on a plane while grasping the objects and the other is that the equilibrium point of the fingertip reaction forces is in the object. Due to these characteristics, the human hand operating the smart mouse has the kinematic configuration similar to a 5-dof parallel manipulator.

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