inFlux: A Magneto-rheological Material Interface

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Abstract

We present a stiffness-changing interface based on a magneto-rheological (MR) fluid. The device consists of a material surface with elecro-magnetically induced visco-elasticity, which acts as a proxy for stiffness during tangible interaction with the material. We present several advantages of this enabling technology and outline potential applications and routes for future development.

Author Keywords

Material; Interface; Magnetic; Ferrofluid; Stiffness; Magnetorheological; Electromagnet

ACM Classification Keywords

H.5.2 [Information interfaces and presentation]: HapticsDeformable Input

Introduction

Tangible interfaces and haptic devices have focused on shape and form change of materials. However, few interfaces have attempted to modulate the mechanical properties of the material. These properties provide feedback to the user during interaction that can be used to convey additional information in addition to the shape of the surface.

The present devices [1, 2] are unable to modify stiffness without volumetric change due to pneumatic actuation be-

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Figure 1: Flux Tangible Interface Device

ing employed. However, in some applications changing shapes to achieve stiffness control is not practical. With Flux interface, we are able to maintain the same volume while still achieving variation in stiffness and an analog control. We present scenarios where such a material will prove useful.

Related work

In HCI, jamsheets [4] explored tunable stiffness using pneumatic particle jamming to control the flexibility of sheet materials. Shape displays [2] have been used to render shapes, but only recently to simulate mechanical properties of materials, and in these cases only indirectly by replicating the associated resulting bulk behavior. Few interfaces are capable of dynamically controlling the stiffness of material via "smart materials." Such materials, including ferrofluid, have been demonstrated in sensing systems as inputs, but less often as outputs. Haptic interfaces utilizing magneto-rheological (MR) fluid have been introduced by Jansen et al. [1] but not explored further, despite several promising advantages. Najmaei et al. [3] proposed the use of MR fluids in actuators for haptic devices. The field of robotics has explored MR fluids in applications requiring controllable adhesion [5, 6].

Principle of Operation

When MR fluid is exposed to magnetic fields, the microparticles align along the magnetic field lines in long chains. These chains resist perturbations, and therefore prevent the flow of the carrier fluid, resulting in an overall increase in apparent viscosity. At a high level, this increase in viscosity causes the material to become more stiff.

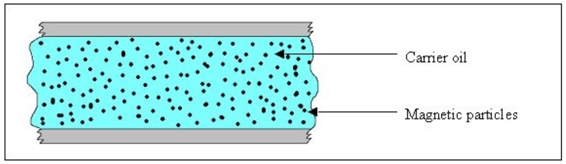

Figure 2: MR Fluid Off State

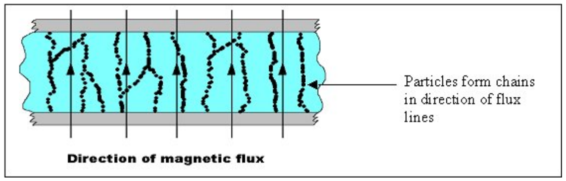

Figure 3: MR Fluid On State

Tunable Material Properties

Compared to other methods to achieve tunable stiffness, MR fluids provide several advantages:

- **Instantaneous Change** Stiffness changes can be achieved with a negligible delay, making this technology suitable for real-time and interactive stiffness control. Furthermore, haptic effects can be achieved by rapidly toggling stiffness, creating a "vibratory" effect, but only during dynamic interaction. Importantly, stiffness cannot be perceived without applying force to the material, which means the user must deform the material to feel these effects.
- **Continuous Stiffness Regime** Because the viscosity of the material is directly related to the applied magnetic field, which can be continuously varied, the resulting stiffness can be set anywhere between a completely "off" state, which is the normal viscosity of the material, and a full "on" state, which is the viscosity under the full power of the electromagnet.
- **Direct Local Control** The material only changes stiffness where under the influence of a magnetic field. Since magnetic fields can be directed towards certain areas, this property allows us to change the stiffness of precise regions of material while leaving adjacent material unaffected.
- **Shape-Independent Stiffness Control** Altering the stiffness of the material does not result in any significant volumetric or shape change. Thus, material properties can be controlled independently of form. Furthermore, this operation is silent and imperceptible through any method other than physical touch. We see this as an advantage for potential applications in discrete interfaces when only the intended user should be able to perceive the transduced information.
- **Simple Design** The operation of the device and the control and actuation system are very straightforward, so the design and prototyping of interfaces based on this technology can be rapid and inexpensive.

Prototype and Technical Design

A basic material element prototype was created consisting of three primary components: the material surface, the actuating electromagnet, and a micro-controller and driving circuitry to control the actuator. The components are mounted inside a housing and additional buttons were integrated to control the material stiffness.

Material

The magneto-rheological (MR) fluid used consists of ferrous micro-particles, in this case iron oxide powder (FE_30_4), suspended in a carrier fluid, in this case common vegetable oil. The viscosity of the mixture depends on the proportion of powder to oil, which was adjusted such that the material has an "off state" viscosity similar to ketchup (100,000 cps). A pouch was fabricated by sealing a flocked elastic membrane to a plastic sheet backing. Approximately 20ml of the mixture was injected into the pouch.

Electromagnet

A 50mm diameter 24V cylindrical electromagnet was used to generate a magnetic field to actuate stiffness change in the material. With approximately 0.3A at full power, this results in over 7W dissipated into the electromagnet. However, with a heat-sink and air cooling system, the resulting heat is not felt by the user.

Electronic Controller

To control the magnetic field, a micro-controller (Arduino Uno), is used to send a Pulse-Width-Modulated (PWM) signal to power MOSFET that drives the electromagnet.

The Arduino also reads input signals from the adjustment knob and controls status lights.

Application Scenarios

There are several immediate applications for this material. Existing interfaces are capable of rendering dynamic, high-resolution visual information (such as common computer screens), and dynamic medium resolution forms and topology (such as Shape Displays). However, interfaces capable of dynamically rendering material properties are uncommon. The ability to instantaneously change the material's stiffness makes it useful for objects that could benefit from rapid changes of rigidity. For instance, a knee pad made out of the material could become stiff only as users are falling down. The rest of the time, the knee pad could remain flexible to improve users' comfort. Sensors such as accelerometers could detect when users are falling and transform the state of the material before they hit the ground.

Another example application is a knife with a blade that contains the material. The blade becomes stiff to cut objects such as food. When users are about to accidentally slice their fingers, the blade automatically becomes flexible to prevent injury. The rapid change of stiffness of the material minimizes the risk of injury.

Applications in which rendering arbitrary material properties could be desirable include: online shopping for certain product classes such as pillows, beds, cloths, etc., haptic feedback for teleoperation, especially in robotic surgery where a variety of different tissues must be discriminated against by contact feedback.

Future Development

There are two obvious avenues of future development for this type of tunable stiffness technology: large scale single element interfaces and interfaces consisting of many of smaller elements.

Stiffness Tunable Support Surface

One promising application of a larger version of this element is in tunable stiffness support and manipulation surfaces, including pillows, beds, chairs, armrests, mobile device cases, etc. Such devices could conform to the user like a water bed, but stiffen to give adjustable support or ergonomic form like a gel or memory-foam. Another application utilizes the instantaneous response of the material to protect the user or device from impact damage. For example, a helmet or knee pad could allow flexibility and comfort during normal use, but instantly stiffen to provide a energy-absorbing cushion when impact is detected.

Stiffness Element Array - Material Displays

Producing very large magnetic fields is difficult because field strength drops with the cube of distance from the source. It is therefor easier to scale the material element down than up. With many small elements arranged in an array, a material surface could be created with higher resolution, similar to Mudpad.[1]

Magnetorheological Elastomers

Another direction for investigation is magneto-rheological elastomers, which consist of ferrmoagnetic microparticles dispersed in an elastic matrix material. Unlike in MR fluids, the material can not flow, so "viscosity" does not change and the particles return to their original relative positions after deformation. However, the stiffness of the material can still be modulated because the particles still try to form chain structures which resist perturbation. Furthermore, the force exerted on the particles by magnetic fields could induce shape changes, including contraction, expansion, and bending.

Future Vision - multiple property control

The long term vision for magnetically actuated tangible interfaces is to achieve control over several mechanical properties of the materials involved, including viscosity, stiffness, density, etc. and to equip these devices with sensors for bidirectional material interaction. When combined in multitudes, such material elements would form a high resolution material display, capable of rendering different material properties in different places and times in highly dynamic ways, all independently of the shape of the material (which can either be completely passive, or actuated separately, as in the contrasting Shape Displays.)

Results & Conclusion

We demonstrated a tangible interface element capable of dynamically changing material stiffness using an electromagnetically activated magneto-rheological fluid. The material can change stiffness rapidly, silently, reversibly, through a continuous range, and independently of shape. We outline several potential applications and routs for future development in this area, including material rendering, conformal support and manipulation surfaces, and material displays.

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