RealWalk: Feeling Ground Surfaces While Walking in Virtual Reality

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Abstract
We present RealWalk, a pair of haptic shoes for HMD-based virtual reality, designed to create realistic sensations of ground surface deformation through MR fluid (Magnetorheological fluid) actuators. RealWalk offers a novel interaction scheme through physical interaction between the shoes and the ground surfaces while walking in a virtual reality space. Our unique approach of using the property of MR fluid creates a variety of ground material deformation such as snow, mud, and dry sand by changing its viscosity when the actuators are pressed by the user's foot. We build an interactive virtual reality application with four different virtual scenes to explore the design space of RealWalk.

Author Keywords
Haptic shoes; haptic interface; virtual reality; VR walking; high fidelity VR experiences; magnetorheological fluid; MR fluid; VR locomotion; multimodal interaction

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces - Haptic I/O

Introduction
Virtual reality is being revived: the emergence of advanced stereoscopic head-mounted displays (HMDs) and 3D graphics technologies offers high-fidelity, immersive VR experi-

Figure 1: (Top) A person with a HMD and RealWalk shoes; (Bottom) A virtual scene with shoes.

ences. With high performance of hardware interfaces and tracking technologies, people are now engaged in more dynamic, whole body activities in a large space such as walking, dancing, and jumping. In fact, walking is one of the most popular form of activities in our daily life and it is now indispensable for interactive virtual reality environment.

As a primary pursuit of virtual reality is the presence and realism, providing realistic sensations of ground surfaces is crucial in order to provide high fidelity of virtual reality experiences. Vibrotactile feedback has been extensively used to deliver the perceived physical texture of ground from the shoes [4, 3] or floor [1]. Taclim[1] is commercial haptic shoes that also adopts vibrotactile actuators for virtual reality to provide different textures of the ground surfaces. However, vibrotactile stimuli have a critical limitation in that their frequency and intensity are limited to express a variety of ground material deformation. Researchers also have reproduced the depth difference of the ground surfaces using a machine with robot kinematics structure [2] or the shoes with slider that makes vertical locomotion [5]. While these approaches show the feasibility of ground material deformation, they still have difficulties to be applied into real world applications of walking scenario due to their spacial requirements of hardware and complicated structures.

We present RealWalk (Fig. 1), a pair of interactive haptic shoes that create a number of realistic sensations of ground surfaces to provide various types of material deformation while users are engaged in walking in virtual reality. We achieve this by using smart fluid based haptic actuators called MR fluid (Magnetorheological fluid) actuators. We believe that RealWalk is a novel interaction scheme that adopts unique property of MR fluid to provide high fidelity walking experiences in virtual reality.

[1] Cervo Taclim: https://taclim.cervo.com/

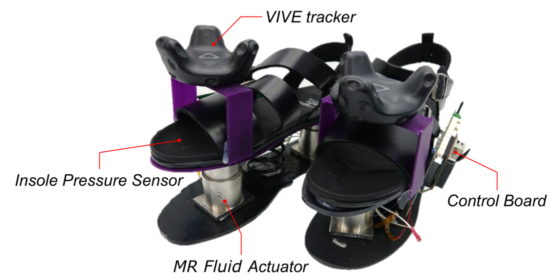

Figure 2: RealWalk haptic shoes.

RealWalk

The main goal of *RealWalk* is to deliver realistic sensations of the ground surfaces by providing different types of material deformation while walking in virtual reality. We accomplish this by specially designed MR fluid actuators. In our MR fluid actuators, various sensations of ground surface deformation can be delivered by varying the magnetic field intensity to rapidly change its viscosity.

A variety of mechanisms have been implemented in RealWalk (Fig. 2). This includes MR fluid actuators, insole pressure sensors with position tracking system, and haptic rendering for multimodal interaction.

MR Fluid Actuators

A key component of physical interaction is MR fluid actuators that we designed and implemented for RealWalk. MR fluid is a type of smart fluid and it immediately changes its viscosity when subjected to a magnetic field. We designed the MR fluid actuators to adaptively adjust the viscosity of MR fluid by varying the magnetic field intensity based on the type of materials in virtual ground surfaces while pressing the actuators with human foot.

Figure 3: (Top) A MR fluid actuator; (Bottom) Components of MR fluid actuator.

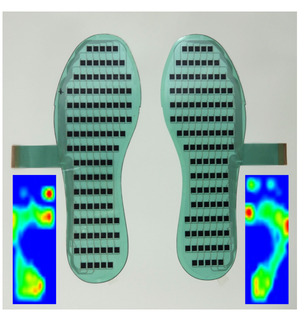

Figure 4: A pair of insole sensors.

In a MR fluid actuator (see Fig. 3), MR fluid is contained in a cylinder along with the magnetic coils. The size of actuator is 55 mm (length) $\times$ 46 mm (width) $\times$ 50 mm (height). A contact cover is placed onto a cylinder with a supporting plate for supporting the force from the foot and creating the resistive force at the same time. A spring is installed between the contact cover and the cylinder for returning the contact cover back to its original position when it is not pressed by the foot. Ultimately, two MR fluid actuators and one external spring are installed between the shoe and a base sole to complete a RealWalk shoe. The locations of two installed actuators (front and rear) are determined based on amount of foot pressure distribution of human walking.

When a user with a shoe (or both shoes) steps on the ground, two MR fluid actuators are depressed. A control board delivers a square waveform with appropriate amplitude and frequency based on the type of ground surfaces and the amount of insole pressure distribution, yielding changes in input current to the magnetic coil. Since MR fluid either increases or decreases its viscosity with respect to the magnetic field derived from input current, the stiffness of fluid is changed accordingly, delivering a variety of tactile sensations while the actuators are pressed by the foot. The maximum of resistive force that an MR actuator can hold is approximately 350N (see Fig. 5).

Insole Pressure Sensor and Foot Position Tracking

RealWalk captures the moment when a shoe makes contact with the ground and how much pressure is distributed over the sole using insole-shaped pressure sensor in the shoe. This insole pressure sensor (see Fig. 4) contains 118 sensing nodes of piezoresistive sensels, with a size of 301.9 mm (length) $\times$ 105.8 mm (width).

A VIVE tracker is also mounted on top of each shoe to

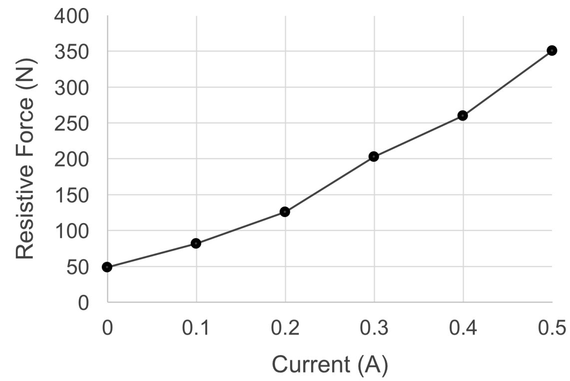

Figure 5: Resistive force measurement with input current. Force measurement is conducted using H5KT Benchtop Tester, Titus Olsen.

precisely track the foot position while the shoe is lifted for the next foot step. In order to complement the reliable foot tracking mechanism, we also use the pressure sensing data from insole pressure sensor when the shoe makes landing to the ground. Our tracking system adaptively adjust the position and movement of the graphical representatives of the shoes by considering both tracking and pressure data from the shoe. Data processing and transmission were controlled by myCortex-STM32F4 board.

Haptic Rendering

We set a number of haptic feedback signal profiles based on the viscoelastic behaviour when undergoing deformation with a range of amplitude and frequency in a square waveform signal (see Table 1). Predefined haptic feedback signal is delivered based on the type of materials of ground surfaces and its intensity is adaptively adjusted based on the amount of insole pressure distribution.

	Amp(V)	Freq(Hz)
Grass	1.65	50
Sand	0.66	150
Mud	2.64	150
Snow	2.97	200

Table 1: Parameters for predefined haptic rendering.

Figure 6: Virtual scenes of the four seasons.

Interaction Scenario

To explore the design space of RealWalk, we built a virtual reality application using Unity3D[2] (version 5.6.0) with four different virtual scenes of the four seasons: spring, summer, autumn, and winter (see Fig. 6). In a spring scene, the grass is covered on the ground surface to provide the characteristics of grass material when the users step on the ground. In a summer scene, users are allowed to walk around the beach and able to feel the deformation of dry sand on their sole. In autumn, users are able to feel the deformation of mud when stepping on the ground surface. Lastly, a winter scene is implemented with snow piled up on the ground. In all four seasons, users are allowed to freely walk around the scenes while wearing both HMD and RealWalk shoes, perceiving different sensations of material deformation of the ground surfaces. The visual footprints are also created along with the appropriate sound effect (i.e. sound of snow crunching) to maximize the realistic walking experiences with multimodal cues in virtual reality.

Conclusion

We presented RealWalk, a pair of haptic shoes that create realistic sensations of ground deformation through physical interaction between the shoes and ground surface using MR fluid actuators. We implemented and integrated a variety of hardware and software modules for RealWalk including MR fluid actuators, insole pressure sensors and foot position tracker, and haptic rendering for multimodal interaction. We also introduced four different virtual scenes of the four seasons to provide a design space for an interaction scenario. We believe that our design of RealWalk can provide the design opportunities to deliver realistic sensations of the ground surfaces to achieve immersive multimodal user experiences while users are engaged in walking in virtual reality.

[2]Unity3D: https://www.unity3d.com/

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