

Wearable haptic-based multi-modal interaction for tangible interface

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Abstract

Innovative developments of information and digital technologies open a new paradigm of lifestyle. Cyber space created by a computer is being developed as a complementary concept to the real world and its practical usage increases drastically. The cyber space technology enlarges the area of human-real world interaction to human-cyber-real world interaction. Tangible interface can be understood as a newly defined concept, which can provide an effective and seamless interaction between the human as a subjective existence and the cyberspace as an objective existence. Our vision is to develop various kinds of tangible interface technologies, by which users can feel reality and seamless integration to the cyber world. Especially, we developed and integrated the haptic technologies for a sense of sight, touch, hearing, and force. The scenario of haptic navigation is experimented for haptic interface with the technologies.

Key words: *tangible interface, wearable haptic device, tactile sensor, tactile display, sound rendering, parametric modeling*

1. Introduction

Recently, cyberspace technologies enable computer users to do the Internet shopping or communication at home and also to obtain entertainment and educational information. But it is possible to experience just visual environments in the cyberspace which does not exchange sufficient information such as tactile feeling, taste, and smell. That is, the cyberspace has been limited in reflecting our physical environments because of the lack of tangibility such as tactile, tasty, and smelling sensibility. Thereby a new project called TSI (tangible space initiative) has been launched by the KIST (Korea institute of science and technology) to overcome the limitations of the cyberspace and to explore a new digital life society [1]. The tangible space has a different concept from the visual cyberspace in that it introduces tangible agent (TA). The tangible agent transfers real world information to computer environment. The real world information includes video, texture, sound, and smell which cannot be experienced due to time and space limits. Also it goes directly to some place and does tasks on behalf of human. For the TA, there are

technologies such as mobile robot manipulation, real-time stereoscopic video, and tactile sensing technologies. The TI(tangible interface) gives human various feelings and information. These two technologies are organically coupled with the cyberspace and build the tangible space. For example, in the tangible space, it is possible for computer users at home to see, smell, touch, and select apples in a remote market or to feel the texture of fabric in a clothing shop and buy it.

The objective of this research is to develop multi-modal haptic interface for the tangible interface. We focus on four human sensing modalities – sight, touch, hearing and force so that we can give the visual rendering, tactile feedback, sound rendering, and passive force feedback. A new mechanism and algorithm for the haptic interface are designed and implemented for each sensing type.

Haptic interface allows a user to touch, explore, paint, and manipulate virtual 3D models in a natural way just as one interacts with the physical environment through the sense of touch. We have developed haptic rendering techniques based on the hybrid surface representation which is a combination of geometric model and volumetric model[2].

Haptic device becomes a new way to a human computer interface. Using a haptic device, the user can easily input position to the virtual environment by moving his or her body. Besides, the haptic device can exert force to the user to express a situation of the environment. But existing haptic devices are too heavy to move wearing it [3-5]. Because the portable device is necessary for an intelligent environment, a small, lightweight and rugged portable haptic device is proposed in this research.

For touch feedback, a new tactile sensor and display system to feel the small shape or texture has been developed. We designed a dynamic texture sensing system with a polyvinylidene fluoride sensor and developed a new signal processing algorithm appropriate for the sensor signals to be registered in an object modeler in cyberspace and to be tangibly displayed by tangible interface systems. In order to display the sensor signal, we also proposed the tactile display unit with high dynamic bandwidth.

In sound rendering, contact sound, which includes

impact and scraping sound, has been the dominant topic, however, operating sound of a machine has been also studied in this paper. Parametric modeling techniques and vibration theory are used to simulate artificial and natural sound. Two examples, sounds of a Korean traditional bell and drilling, are explained in detail as sound rendering examples.

The paper is composed of four sessions. In section 2, we introduce the organization of the haptic interface and four components for multi-modal interaction. Section 3 gives the idea of the scenario for the haptic interface. Conclusion and some future work are remarked in Session 4.

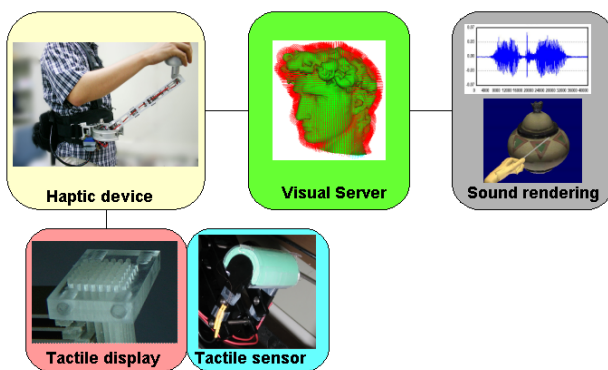


Fig.1 A diagram of multi-modal interface

2. Multi-modal Interaction

In order to enhance reality of tangible space, the multi modal interface which stimulates various human senses altogether is absolutely necessary. In our research, the interface is composed of wearable haptic device, tactile sensor and display, sound rendering, and visual haptic rendering as shown in Fig. 1. Each component corresponds to the sense of force, touch, hearing and sight. The visual server gives the kinesthetic information including collision detection to haptic device which responds by reporting the end coordination of itself and transfers the information to the tactile display unit. The visual server also provides the sound rendering part with the information.

A. Wearable Haptic Device

A new lightweight wearable haptic device is developed, as shown in Fig. 2. The base linkage is designed as a serial RRP(rotation-rotation-prismatic) mechanism to measure a translation, and a RRR z-y-z rotation mechanism is attached at the end of the base linkage for rotation.

The prismatic joint, the third joint in the base mechanism is composed of three pieces of links that slide into each other as shown Fig. 2. The sliding links design makes the device compact in folded configuration, and also it covers large workspace when it extends.

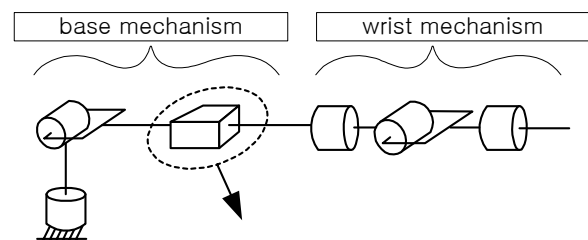
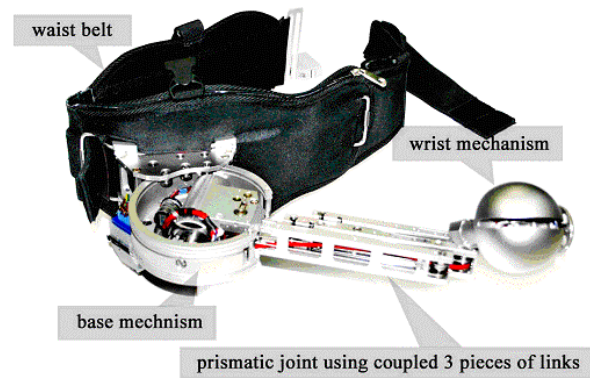


Fig 2. Picture of developed wearable haptic device

Table 1. Specification of Wearable haptic device

Degree of freedom	6 (3) ^a
Max continuous feedback force	10 N
Workspace	550mm hemisphere
Weight	2.2 kg (3.8 Kg) ^b
Operation time	1.5 hour

^a for force feed back

^b Including standalone controller and battery

To achieve a compact design and reduce its weight, a novel tendon driven mechanism is designed at each joint. Particularly, each sliding link has a pulley and two tendon loops are built in the prismatic joint. The one is for making constraint and the other is for actuation. The three sliding links are kinematically coupled by tendon. Consequently, the three links moves like a one degree-of-freedom prismatic joint.

Due to weight constraints, only three passive actuators are installed for force feedback, and each actuator is specially designed to fit the joint. Because a passive actuator is better than an active one in terms of power density (power per unit volume or weight), a small MR (Magneto-rheological) brake has been developed. It is installed at each joint of the base linkage for 3-DOF force feedback. Also a compact brake drive with current feedback capability has been designed which enables to reduce the response time of the MR brake.

In tele-manipulation, the user can use whole 6 degrees of freedom as an input device, while 3 degree-of-freedom force feedback is available.

The controller is packed into a bag which is attached on

back side of waist. Because it includes brake drivers, satellite controllers, wireless LAN and battery, it can operate stand-alone. The specifications of the haptic master are summarized as shown table 1.

B. Tactile Sensor & Display

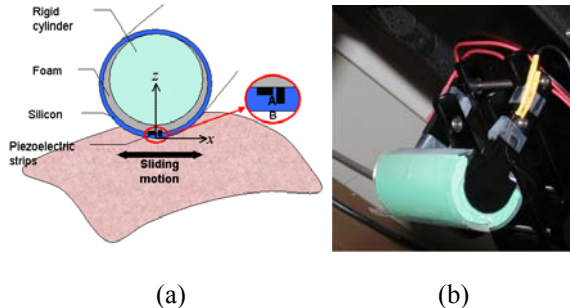


Fig.3 (a) Cross sectional view of a sensor module (b) PVDF sensor module

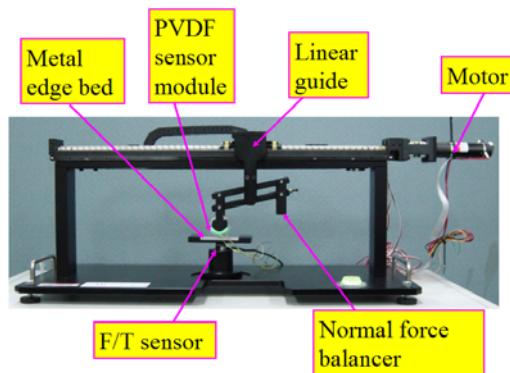


Fig. 4 A scanning mechanism for modeling of PVDF sensor with FT sensor

As is shown in Fig. 3(a), a PVDF sensor module similar to what was developed in [6] is made to obtain estimated normal and shear force when the sensor module slides on the surface of a material which we want to scan. Two strips of piezostrip which has 30 μm thickness, 0.5mm width, and 35mm length are molded into the flexible silicon cover. The picture of the developed PVDF sensor module is shown in Fig. 3(b). Two strips are located perpendicular to each other, and as closely located as possible. A piece of foam rubber is inserted between a rigid cylinder and the silicon rubber for a good contact condition. To obtain the texture information for various kind of materials, a new scanning system is developed as shown in Fig. 4. Rotation of a DC motor is converted to linear motion by a ball screw which gives 10 (mm) movement per one revolution. A simple balancing mechanism is attached to the PVDF sensor module in order to maintain a uniform normal force condition while linear motion is being performed.

The restoration problem is to transform from the stress rate signals of the PVDF strips at the location A into two estimated surface line forces and other texture

components. Dynamic relation from measured signals to the forces is directly modeled in one-step with a nonlinear MIMO (multi-input multi-output) ARMAX (autoregressive moving average) model, which does not need forward modeling from the surface forces to the measured sensor signals, and a time domain least squares estimation technique[7].

In order to show the force or displacement signal restored by the tactile sensor, a new type tactile display unit is designed. Its unit is comprised of a pin array and eight piezoelectric bimorphs for normal vibrotactile stimulation. A piezoelectric bimorph has higher degree of stiffness, a larger displacement, and a lower operating voltage ($\pm 60\text{V}$) than typical piezoelectric actuators. In addition, its response time is in the millisecond range and it can provide a force of up to 1 N which is sufficient to press the skin with a deformation of 1mm. Piezoelectric bimorphs are clamped with 1 mm spacing and the 8 x 1 pin array is attached at the end of one bimorph. The pin spacing is 1mm and the diameter of each pin is 0.5 mm, enabling the display of a texture 8 mm wide. The results of our experiment revealed that bending actuator could travel up to 1mm in 200Hz frequency range, and it generated enough vibration to stimulate the skin at over 800Hz[8].

We also add an ability of thermal display to the tactile display unit. Even with the exact same roughness, a human can distinguish materials by thermal conductivity. We cover the pin array with a thermoelectric module called a peltier heat pump and a copper plate which can transfer heat fast. The module can transfer heat with maximum $+15.6^\circ\text{C/s}$ and -4.5°C/s .

The developed tactile display unit is located at the end tip of the haptic device so that a human can put his finger on the unit as shown in Fig. 5.



Fig. 5 the tactile display unit integrated with the haptic device

C. Sound Rendering

For the final demonstration three sound rendering examples have been studied. They are door opening sound, stone scraping sound, and Korean traditional bell sound. Various techniques have been studied to simulate the real sound. Korean bell sound case is explained in

this paper. King Seong-deok divine bell is selected as a Korean bell sound. The bell sound has a very distinctive long-lasting beats. The sound has very close natural frequency pairs caused by bell's symmetric shape. It has eighteen modes below 350 Hz.[9,10] Table 2 shows first four modes. f , ϕ , ζ , A represent phase delay, natural frequency, damping, and amplitude of each mode respectively. As expected, the first and second modes are very similar and the third and fourth modes also show very similar characteristics.

Table 2 first four modal parameters of the King Seong-deok divine bell

Parameters	Low(0,2) mode	High(0,2) mode	Low(0,3) mode	High(0,3) mode
ϕ	0.642 rad	-0.143 rad	-0.267 rad	0.276 rad
f	64.07 Hz	64.42 Hz	168.52 Hz	168.63 Hz
ζ	0.00013	0.00013	0.00030	0.00030
A	1	0.1	0.5	0.5

Using analyzed sound data, following equation(1) is used to generate simulated bell sound.

$$y(t) = \sum_{i=1}^N A_i \cdot e^{-\zeta_i 2\pi f_i t} \cdot \sin(2\pi f_i \sqrt{1-\zeta_i^2} t + \phi_i) \quad (1)$$

Fig.6 shows simulated bell sound using first four modes. There are two beats. In the figure, the first beat caused by the first two modes is clear and the second beat has disappeared very fast because of relatively higher damping value.

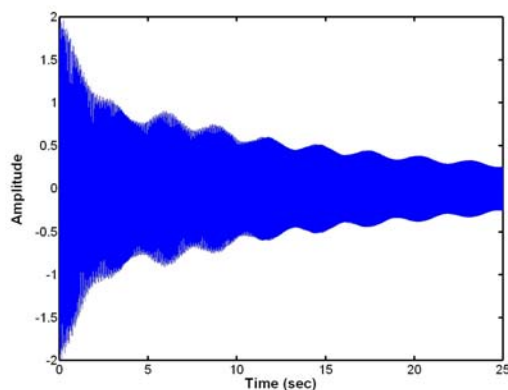


Fig. 6 Synthesized bell sound from first 4 modes

The AR modeling[11] is used to simulate small drill sound for dental simulator. Separate computer equipped with DSP is used for simulation sound calculation and TCP/IP is used for communication with simulator computer to get information on power switch on/off, contact, and contact area. Drilling sound at idling and working is sampled and modeled as the AR model as in

equation(2).

$$y(t) = a_1 \cdot y(t-1) + \dots + a_M \cdot y(t-N) + e(t) \quad (2)$$

where M is model order, a_1, \dots, a_M are AR coefficients, and $e(t)$ is Gaussian noise. AR(300) model is selected and volume of drilling sound is adjusted according to contact area information to enhance reality. Fig. 7(a) shows the spectrum of real and simulated sound at idling and working condition. Solid lines show spectrum of real sound and dotted lines show spectrum of simulated sound. The spectrums of simulated sound show very similar characteristics. Fig. 7(b) shows dental simulator under development.

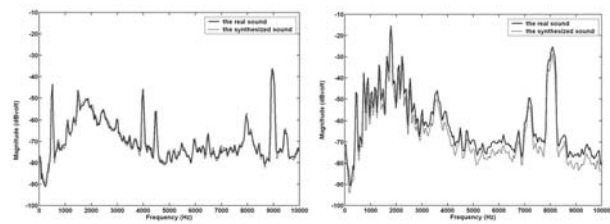


Fig. 7 (a) Sound spectrum of idling condition (b) Sound spectrum of drilling condition

D. Visual Rendering

In this section, we describe visual and haptic rendering algorithm based on a hybrid surface representation for desktop haptic system. Geometric model is used for visual display and volumetric implicit surface for haptic rendering.

Data representation

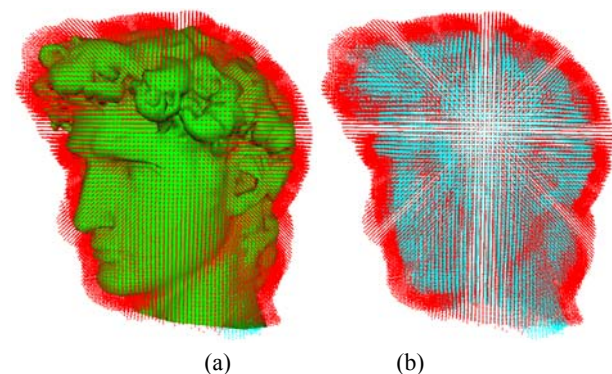


Fig 8. Model conversion from geometric model (david) into volumetric implicit surface using Mauch's closest point transform algorithm. (a) geometric model and its volumetric model. (b) volumetric implicit surface

Our algorithm is based on a hybrid surface representation a combination of geometric (B-rep) and implicit (V-rep) surface representations for a given 3D object, which takes advantage of both surface representations. For the visual display, the geometric model can effectively represent the 3D model compared to volume rendering. Meanwhile, the implicit surface

representation has many properties that address the limitations of current geometric haptic algorithms and introduce new haptic and visual effects. The volumetric implicit surface is obtained from a geometric model using Mauch's closest point transform algorithm (see Fig. 8).

In the volumetric representation, only potential values close to the implicit surface are involved in the computation (see Fig. 9). The potential values inside the close neighborhood of the surface range from -1 to 1 according to the proximity to the closet point on the surface. The values inside the surface are negative and positive outside. The values out of this narrow band are nothing to do with the surface modeling and haptic rendering. Therefore, to reduce the memory requirement, we use an octree-based data structure, avoiding the representation of empty portions of the space.

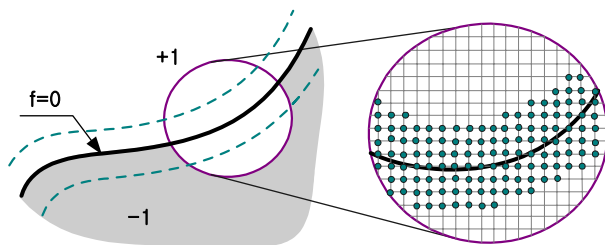


Fig 9. Volumetric representation

Force model

Based on an implicit surface representation, collision detection becomes trivial due to the inside/outside property. If the potential value at the virtual tool position is less than 0 (inside the surface), a collision is detected. The force direction is computed by interpolating the gradients of 8 cell points around the virtual tool. The interpolation function leads the system to avoid the force discontinuity.

In order to determine the amount of force, the system finds the virtual contact point (VCP) on a surface which is the intersection point between the surface and a ray along the computed force direction from the tool tip point. The amount of force is proportional to the distance between the VCP and the tool tip. Once the VCP is determined, a spring-damper model is used for force control to make the system stable as follows:

$$F = k * (p_c - p_t) + b * V \quad (3)$$

where F is the force vector, p_c and p_t are coordinates and the VCP and tool tip in 3D space respectively, V is the difference in velocities of the VCP and tool tip, k is stiffness constant, and b is viscosity constant. Spring stiffness has a reasonably high value and viscosity is to prevent oscillations.

3. Experiments: haptic navigation

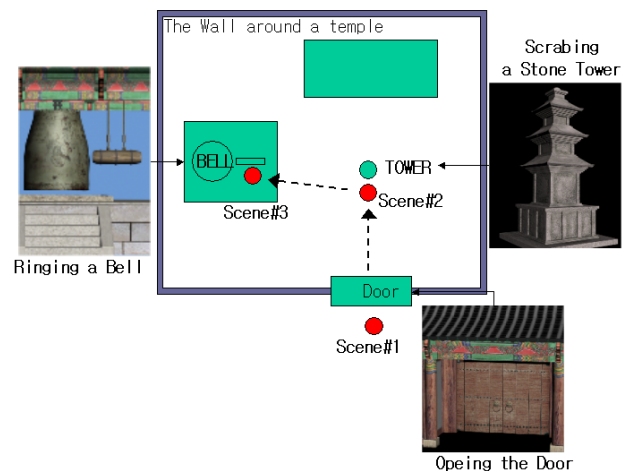


Fig. 10. Scenes of haptic navigation scenario: to open the door, to touch a stone tower, and to ring a big bell



Fig.11 View of an operator

In the scenario of haptic navigation, an operator is going to experience three different scenes which are opening a door, feeling a stone tower, and ringing a bell as shown in Fig. 10. The operator moves in the virtual space, and he sees 3-D scenes of the scenario with the hand avatar which visualize the position and current state of the operator's hand as shown in Fig. 11. When the operator wants to jump to the next scene, he can just push the red button on the screen.

At the first scene, the operator can open and feel the door. The operator moves the avatar hand on the screen by manipulating the haptic device. When the avatar hand meets the door, the door begins to open. The visual server sends the information of collision depth and direction to the haptic device, which exerts the computed force to the arm of the operator. The sound rendering generates the sound of opening whose main parameter is an angular velocity of the door. The tactile display also makes the sine wave, carved on the surface of the door, waving along the vertical motion of the haptic device.

The second scene allows the operator to touch and slide

on the surface of the a stone tower shown in Fig. 10. The haptic device forces the arm to move along the vertical surface of the tower while the tactile display sends the restored signal form the tactile sensor to the second finger of the operator. The tactile signal composed of 3mm wave and 0.5mm vibration is obtained by scanning a rough brick with the tactile sensor. Scratching sound is also generated by the sound rendering.

At the final scene, the operator grabs the wire of a bell hammer and hits the bell. As you expected, the haptic device makes a repulsive force and ringing sound spreads out. Additionally, the operator can touch the bell to feel the cold surface by the thermal display unit.

4. Conclusion

In this research, we proposed the concept of Tangible Space and developed multi-modal haptic interface component implementing force, touch, sound, and visual feedback which are realized by the new type haptic device, tactile sensor and display system, sound rendering, and visual rendering. With the scenario of the haptic navigation, we integrated all components into the scenario. The system we integrated is just the beginning of the tangible interface. In the future, we will improve performance of each component; we expect to give more realistic feeling to people in the Tangible Space.

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