Force Display for Virtual Worlds

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ABSTRACT

In proportion to the generalization of virtual reality, need for force-feedback is recognized. The major objective of our research is development of force-feedback devices for virtual worlds. Following three categories of force displays are developed:
(1) Desktop Force Display
A compact 9 degree-of-freedom manipulator has been developed as a tactile input device. The manipulator applies reaction forces to the fingers and palm of the operator. The generated forces are calculated from a solid model of the virtual space. The performance of the system is exemplified in manipulation of virtual solid objects such as a mockup for industrial design.
(2)Texture Display
Active touch of an index finger is simulated by 2 DOF small master manipulator. Uneven surface of a virtual object is presented by controlling a direction ofthe reaction force vector.
(3)Force Display for Walkthrough This system creates an illusion of walking through large scale virtual spaces such as buildings or urban space.The walker wears omni directional sliding devices on the feet, which generate feel of walking while position of the walker is fixed in the physical world. The system provides feeling of uneven surface of a virtual space, such as a staircase.While the walker goes up or down stairs, the feet are pulled by strings in order to apply reaction force from the surface.

1.INTRODUCTION

The recent evolution of intelligent systems requires natural communication between machines and human beings. A configuration of human interface called "artificial reality" is expected to improve human-computer interaction. The major objective of research on artificial reality hasbeen focused on display device for visual information. Various methods forhead mounted display have been developed. Through applications of head-mounted displays to virtual space operation system, need for force-feedback has generally recognized. One of the primary object of our research is implementation of force-feedback in desktop virtual worlds. Compared to presentation of visual and auditory information, methods for presenting tactile information have not been sufficiently developed. Here are 3 classes of tactile input devices:
(1) master manipulator
(2) 3 dimensional mouse
(3) glove
There have been 3 dimensional mice with a force-feedback handle controlled by nine strings. An example device, called "JoyString", was developed by Agroninin 1987. These devices generate 6 degree-of-freedom reaction force, buttheir working volume is limited and there are singularities in theirworking spaces. In the field of robotics research, master manipulators are used in teleoperation. Some examples of master-slave manipulators have ability of teleperception of remote objects. Most master manipulators, however, have large hardware with high cost, which restricts their application areas. In our research, a compact master manipulator has been developed as a tactile input device on a desktop[1][2]. The manipulator generates reaction force to the palm and the fingers of the operator. Application areas of the system are focused on CAD/CAE or industrial design.

Large scale virtual worlds such as buildings or urban space are also targets of our research. Simulating virtual buildings, before they are physically constructed, is useful for designers and clients. This paper presents method of creating sense of walking through virtual rooms, passages, and staircases[3][4].

2. DESKTOP FORCE DISPLAY

2-1. Basic Structure of the System

The virtual object manipulation system is composed of two subsystems, a real-time graphic display system and a master manipulator for tactile input and reaction force generation. A specialized graphics computer provides a real-time image of virtual space. The overall configuration of the system is shown in Figure 1.

A mirror is set in front of an operator's eyes at angle of 45 degrees, which reflects the image on the CRT screen. The operator can not see the physical world, only the virtual world which includes their hand. This optical configuration immerses the operator in the computer generated virtual space. Articulated graphics of a hand is displayed corresponding with the position and orientation of operator's hand as obtained from the manipulator. Overall view of the system is shown in Figure 2.

A personal computer provides I/O control of the analog-to-digital (A/D) and the digital-to-analog (D/A) convertors for the manipulator. The graphics and I/O processors are connected by a serial (RS-232C) communication line.

The graphics computer is a Stardent TITAN; the I/O processor is a NEC PC-9801.

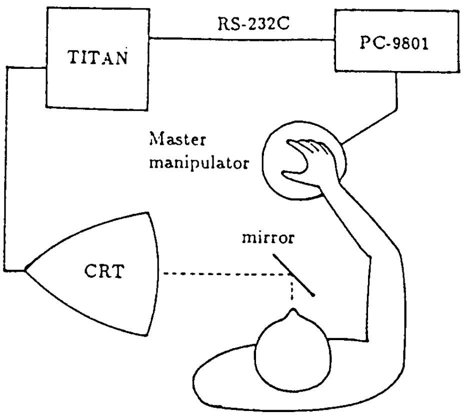

Figure 1. Hardware configuration of the desktop force display

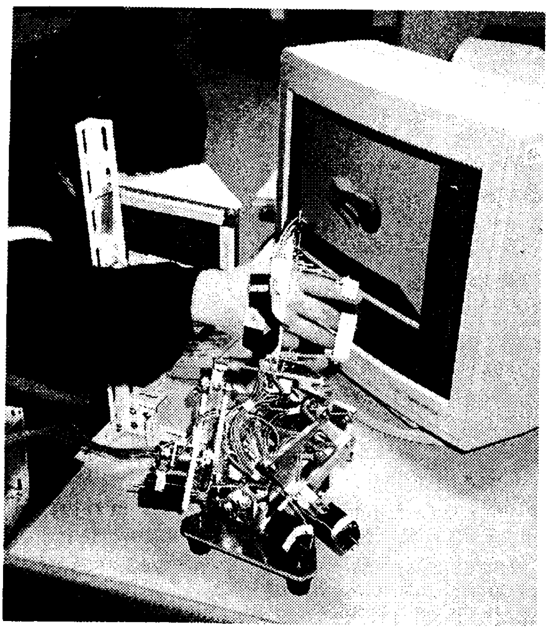

Figure 2. Overall view of the system

2-2 Compact Mater Manipulator

A 9 degree-of-freedom manipulator was developed as a tactile input device with reaction force generator (master manipulator). The manipulatorapplies reaction forces to the fingers and palm of the operator. The core element of the subsystem is 6 degree-of-freedom parallel manipulator. The typical design feature of parallel manipulators is an octahedron, in which a top triangular platform and a base triangular platform are connected by six length-controllable cylinders . This compact hardware has the ability to carry a large payload. The structure, however, has some practical disadvantages in its small working volume and its lack of backdrivability (reduction of friction) of the mechanism.

In our system, three sets of pantograph link mechanisms are employed instead of linear actuators. The mechanism is illustrated in Figure 3. Each pantograph is driven by two DC motors. The top end of the pantograph is connected with a vertex of the top platform by a spherical joint.This mechanical configuration has the same advantages as an octahedron mechanism has. The pantograph mechanism improves the working volume and backdrivability of the parallel manipulator. The working space of the center of the top platform is a spherical volume whose diameter is approximately 30 cm. The maximum payload of the parallel manipulator is 2.3 Kg, which is more than a

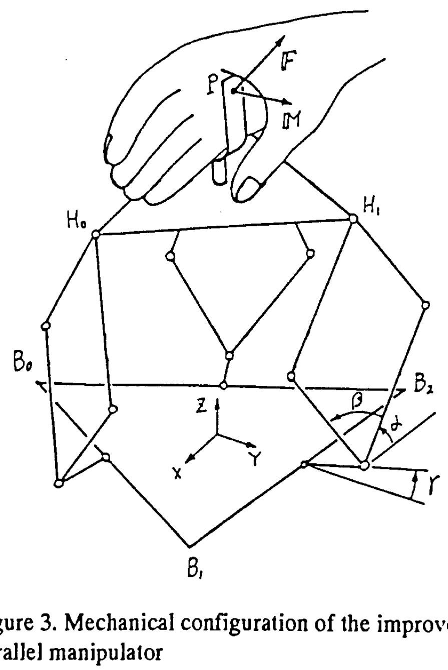

Figure 3. Mechanical configuration of the improved parallel manipulator

typical hand. Each joint angle of the manipulator is measured by potentiometers. Linearity of the potentiometers is 1%. The non-linearity is not corrected in the current system.

The top platform of the parallel manipulator is fixed to the palm of the operator by a U-shaped attachment, which enables the operator to move the hand and fingers independently. Three actuators are set coaxially with the first joint of the thumb, forefinger and middle finger of the operator . The last 3 fingers work together. DC servo motors are employed for each actuator. The maximum torque at each actuator shaft is 3 Kgcm. Working angle of the thumb is 120 degrees and that of the other fingers are 90 degrees.

2-3. Method of Manipulation of Virtual Solid Objects

The contact of the virtual hand with virtual objects is detected at the 16 control points shown in Figure 10. The distance between these points and the surface of a virtual object is calculated. If the thumb and one of other fingers touches a virtual object, the object is regarded as captured. After the capture, virtual object coordinates are fixed to the hand coordinates so that the object moves with hand as though gripped.

Reaction forces to the fingers are generated according to the solidity of the captured object. If the object is a rigid body, the maximum possible torque is transmitted to the fingers to present the hard surface of the object. The force and moment vector at the palm is determined with respect to the position of palm and the object, according to the mass distribution of the object.

3.TEXTURE DISPLAY

Force display is especially useful for presentation of surface texture of virtual objects. We have developed 2 degree-of-freedom master manipulator for texture display[5]. The mechanical configuration of the manipulator is illustrated in Figure 4. The manipulator enables active touch of index finger, which is natural action in exploration of surface texture of physical objects. 2 DC motors generates reaction force from the virtual surface. Uneven surface of virtual objects is presented by controlling a direction of the reaction force vector(See Figure 5).

4. WALK THROUGH SIMULATOR

4.1 Basic Idea of the Walkthrough Simulator

A head-mounted display provides 360-degree image of a virtual space. However, walkable area of the virtual space

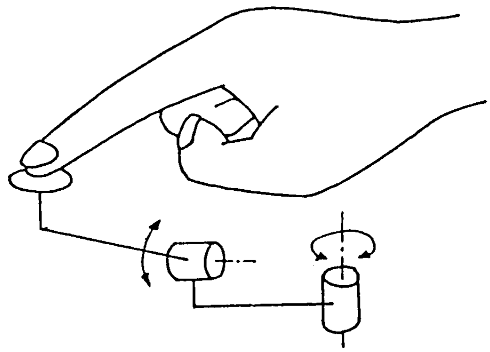

Figure 4. Mechanical configuration of the texture display

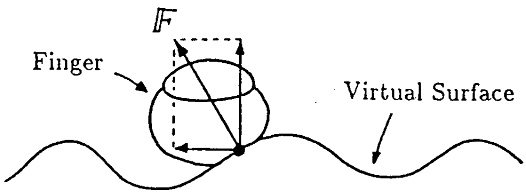

Figure 5. Method of presentation of virtual surface

is strictly limited according to the sensing range of the 3-space magnetic sensor or wire harness of the tactile input device. A possible method for exploring a virtual space is hand gesture. Current system for virtual reality, such as VPL's, uses index finger to point a direction. Since the research objective of virtual reality is simulation of a virtual space corresponding with human senses, haptic feedback for legs is essential for natural interaction.

The primary object of our research is presenting sense of walking while position of the walker is fixed in the physical world. Through some feasibility studies[3][4], we found a method of virtual walking. The basic idea of a prototype system is illustrated in Figure 6. The trunk of the walker is fixed to the framework of the system by safety harness. The harness does not restrict the motion of the legs and arms. The walker wares omni directional sliding devices on the feet, which enable the walker to turn left or right. The motion of the feet and the head is measured by ultrasonic sensors. From the result of measurement, image of the virtual space is displayed in the head-mounted display corresponding with the motion of the walker. Friction forces from the floor are generated by the sliding device. The system provides feeling of uneven surface of the virtual space, such as staircase. While the walker goes up or down stairs, the feet are pulled by strings in order to apply

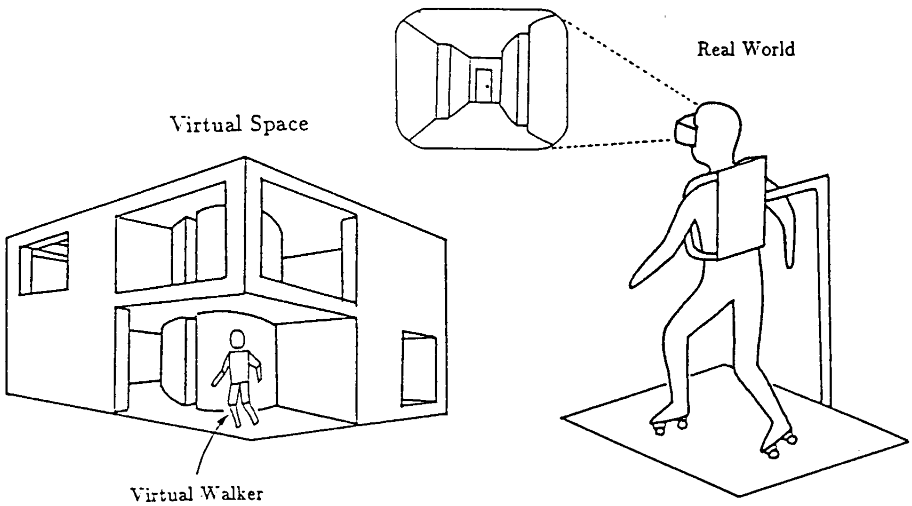

Figure 6. Basic idea of virtaul walking

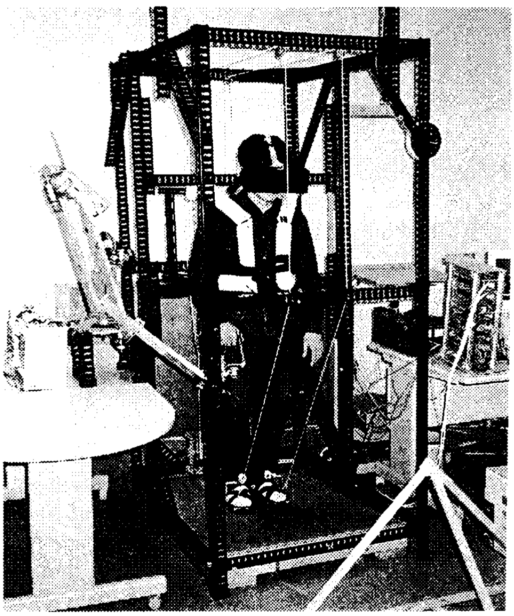

Figure. 7. Overall view of the walkthrough simulator

reaction forces from the surface. A 6 degree-of-freedom master manipulator is developed to apply reaction force to the hand. The manipulator generates 3 degree-of-freedom force and 3 degree-of-freedom torque, which enables the walker to feel weight of a door in a virtual building. Overall view of the system is shown in Figure 7.

4-2. Hardware Configuration

The hardware configuration of the system is indicated in Figure 8. The system employs two computers:a graphics computer for real-time image of a virtual space and an I/O computer which supervises sensors and actuators.

(1) Graphic computer and display

Image of the virtual space is generated by a personal computer and a graphics accelerator. The inexpensive accelerator named "Personal HOOPS" (KOBELCO Corp.) provides real-time image. This apparatus employs two Transputers: a T800(10Mips) for coordinate transformation and a T414(10Mips) for rendering. Development of our graphics application is supported by its HOOPS library. The graphics performance is 125K 3-D vectors/sec. The update rate of the image is 3 Hz in case of a simple room with stairs. The personal computer manages a solid model of the virtual space. The image on the CRT of the Personal HOOPS is converted to NTSC standard video signal, and sent to the HMD(head-mouted display). Two 2.7-inches liquid crystal displays are mounted on the HMD, which presents stereoscopic image. The optical configuration is illustrated in Figure 5. The effective field of view is 30 degrees.

(2) I/O computer, sensors and actuators

The I/O computer supervises ultrasonic sensors, string tensioners and a master manipulator. Ultrasonic sensors and string tensioners are interfaced to the personal computer by PIO(parallel input and output unit). The master manipulator is controlled by board computer equipped with 16-bit micro processor. This unit is interfaced to the personal computer by serial (RS-232C) communication line. The I/O computer transmits motion data of the walker to the graphics computer by RS-232C, and receives reaction force data.

4-3. Method of Virtual Walking

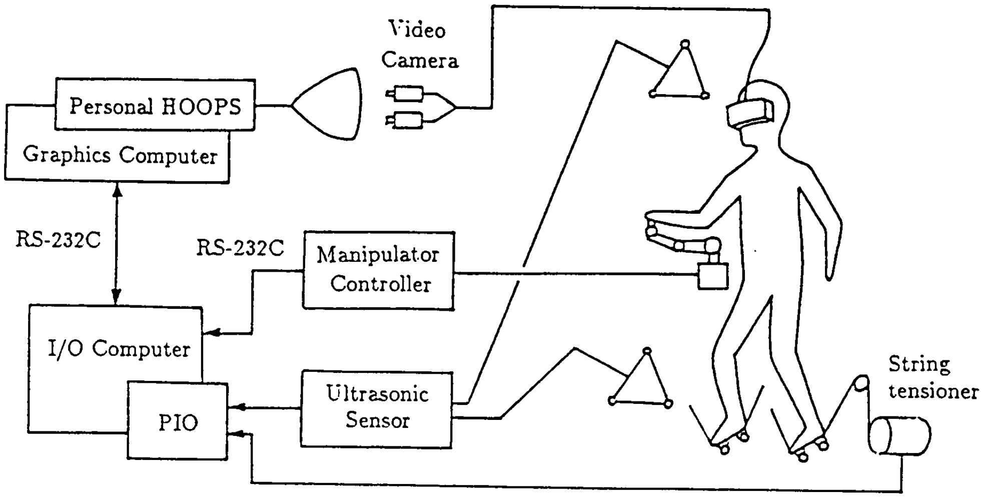

FIgure 8. Hardware configuraton of the walkthrough simulator

(1) Sliding device

A simple device for virtual walking is a moving belt, ordinary used for physical fitness. Application of this device to virtual building simulator is developed in UNC. However, it only allows the walker to straight forward motion. A 2 dimensional sliding device is required for the walker to change the direction. We developed specialized roller skate equipped with 4 steel balls, which enables 2 dimensional motion.

(2) Motion tracking

The motion of the head and feet are measured by ultrasonic sensors. These sensors are composed of ultrasonic transmitters and receivers. The distance between those components are determined by the required time for propagation of an ultrasonic wave. Two transmitters and three receivers are used to triangulate the position of the feet. Sampling rate of each sensor is 20 Hz. The personal computer calculates the triangulation in 5 msec. The CPU of the computer is 8086(8MHz) with 8087. Precision of the measurement is 1 cm.

The motion of the head is tracked by same sensor system as the feet. Two transmitters are mounted on the HMD. Yaw and pitch motion of the head are detected. Roll motion is neglected in the current system, since this degree-of-freedom is less important in exploring a virtual space. Scene of a virtual space is generated corresponding with the results of motion tracking of the head and feet.

(3) Actuation

Typical force display devices are master manipulators. In case of virtual walking, however, the maximum requested reaction force from the floor is amount to the weight of the walker. The heavy payload requires large hardware of master manipulators, which obstructs natural motion of the walker. For this reason, strings are used for force display devices in our system. The position of the pulleys are determined so as the string does not interfere the motion of the head and arms. The sliding device is pulled by the string. The tension of the string is generated by a DC motor. In our current system, the maximum generated tension is 22 Kgf. The length of the string is measured by a rotary encoder set coaxially with the motor pulley. This apparatus is served for each foot.

4-4.Application Areas

Application of the walk through simulator can be focused on following fields:

(1)Design of buildings and equipments
- designer-client dialogues in constructing homes or shops
- collision detection of equipments in large scale plants such as a nuclear reactor

(2)User interface for multi-media database
- displaying stored data in a virtual museum

(3)Entertainment and health
- taking a walk in a virtual tourist resort

(4)Welfare
-aid for rehabilitation

5. CONCLUSION

This paper has shown our current works on force displays.Generally, research on artificial reality technology is still at an early stage. Although various techniques have been proposed, theory for designing virtual environments has not been established. Future direction of our research is study on human factors or cognitive characteristics of virtual worlds.

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