Exploring Haptic Displays in Virtual Reality

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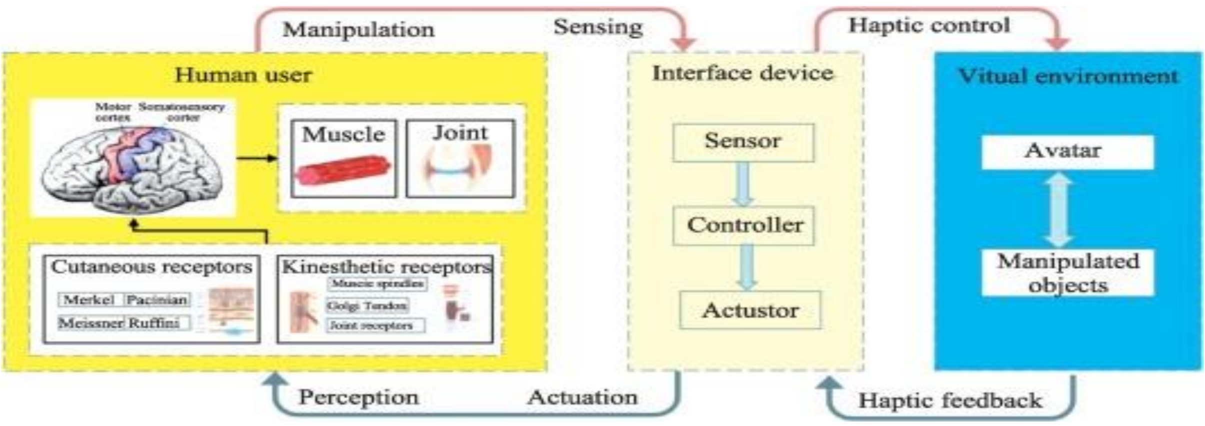
Immersion, interaction, and imagination are three features of virtual reality (VR). Existing VR systems possess fairly realistic visual and auditory feedbacks, and however, are poor with haptic feedback, by means of which human can perceive the physical world via abundant haptic properties. Haptic display is an interface aiming to enable bilateral signal communications between human and computer, and thus to greatly enhance the immersion and interaction of VR systems. This paper surveys the paradigm shift of haptic display occurred in the past 30 years, which is classified into three stages, including desktop haptics, surface haptics, and wearable haptics. The driving forces, key technologies and typical applications in each stage are critically reviewed. Toward the future high-fidelity VR interaction, research challenges are highlighted concerning handheld haptic device, multimodal haptic device, and high fidelity haptic rendering. In the end, the importance of understanding human haptic perception for designing effective haptic devices is addressed.

Introduction:

In 1965, Ivan Sutherland proposed the concept "the ultimate display", which represents the birth of virtual reality (VR). Haptic feedback is indispensable for enhancing immersion, interaction, and imagination of VR systems. Interaction can be enhanced by haptic feedback as users can directly manipulate virtual objects, and obtain immediate haptic feedback. Immersion of the VR system can be enhanced in terms of providing more realistic sensation to mimic the physical interaction process. Imagination of users can be inspired when haptics can provide more cues for user to mentally construct an imagined virtual world beyond spatial and/ or temporal limitations.

The haptic sensation obtained through virtual interaction is severely poor compared to the sensation obtained through physical interaction. In our physical life, the haptic channel is pervasively used, such as perception of stiffness, roughness and temperature of the objects in external world, or manipulation of these objects and motion or force control tasks such as grasping, touching or walking etc. In contrary, in virtual world, haptic experiences are fairly poor in both quantity and quality. Most commercial VR games and movies only provide visual and auditory feedbacks, and a few of them provide simple haptic feedback such as vibrations. With the booming of VR in many areas such as medical simulation and product design, there is an urgent requirement to improve the realism of haptic feedback for VR systems, and thus to achieve equivalent sensation comparable to the interaction in a physical world.

Paradigms of haptic display driven by computing platform:



As shown in above figure the paradigm of human-computer interaction (HCI) can be defined with three components: human user, interface device, and virtual environment synthesized by computer.

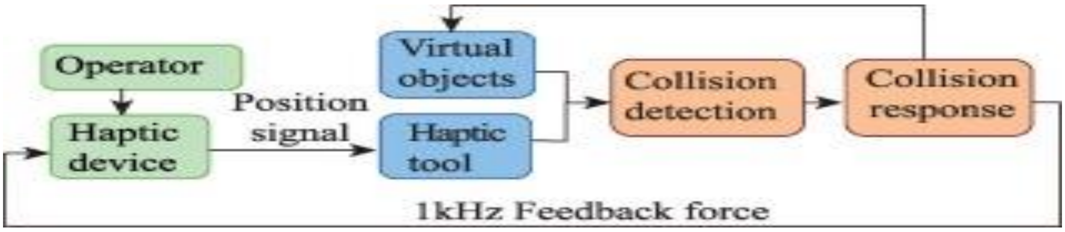
Considering the human user, we need to study both the perception and manipulation characteristics of the haptic channel during the bilateral communication between human and computer. For the perception aspect, human perceptual system mainly includes diverse kinesthetic and cutaneous receptors in our body, which located in skin, muscles or tendons. For the manipulation / action aspect, we need to consider the motor control parameters, including degree-of-freedom (DoF) of motion or force tasks, the magnitude and resolution for motion and force signals for diverse manipulation tasks.

Considering the interface device, its functions include sensing and actuation. For sensing, a device needs to sense / track human manipulation information such as motion / force signals, and then transmit this information to control a virtual avatar of the device in the virtual environment. For actuation, the device receives simulated force signals from the virtual environment, and then reproduces these forces by actuators such as electric motors to exert these forces on user’s body.

Considering the virtual environment, diverse tasks can be simulated, including surgical simulation, mechanical assembly, computer games etc. Whenever there are direct contacts between the user-driven avatar and the manipulated objects, haptic feedback devices can be used to display the resultant contact forces/torques to users.

Haptic rendering

Haptic rendering refers to the process of computing and generating forces in response to user interactions with virtual objects. Below figure shows the pipeline of haptic rendering.

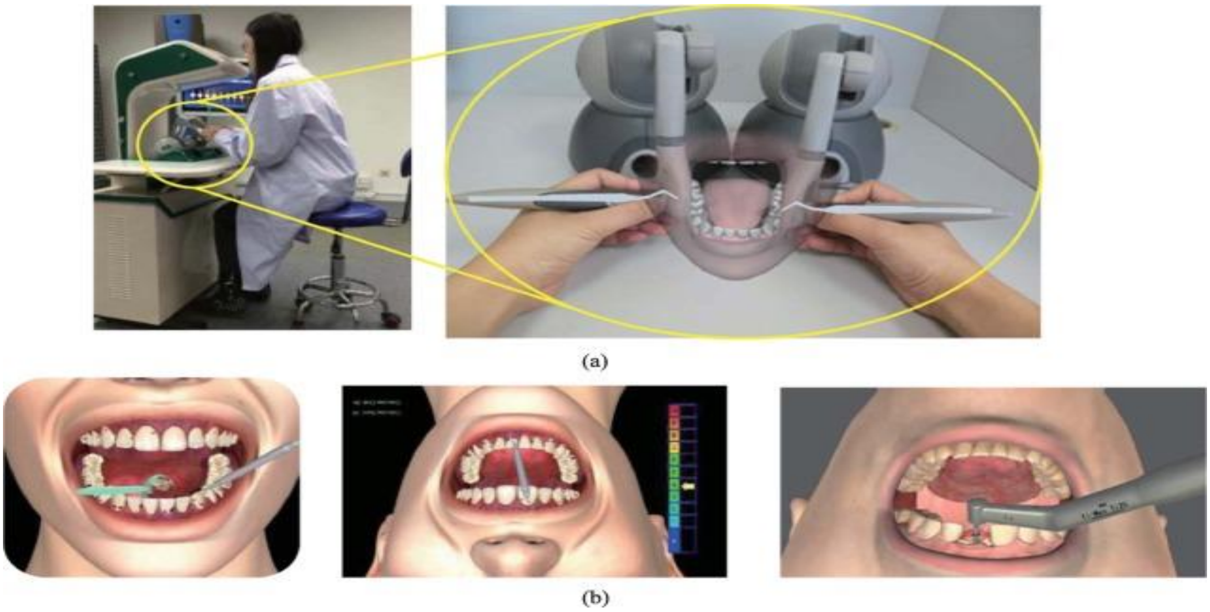


The development of haptic rendering algorithms can be attributed to the driving forces from both the advancement of force feedback devices and the requirements of force feedback applications. The principle is to represent the virtual avatar of the handhold device as a point with three dimensional motions, which can interact with objects of virtual environment and produce three dimensional forces. Then the forces are fed back to the operator by the stylus of the force feedback device to make the operator feel contact forces between the virtual avatar and virtual objects. Due to the demand driven in different application fields, various 3-DoF haptic rendering algorithms have been studied, including rigid body interaction, elastic body interaction, fluid simulation and topological changing force interaction. The classical algorithms include: god-object, virtual proxy, ray casting.

Applications:

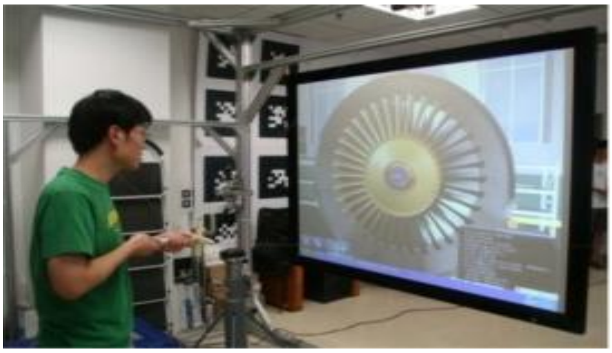
Typical application of desktop haptic systems include virtual surgery, mechanical assembly, and other tool-based entertainment such as virtual sculpture.

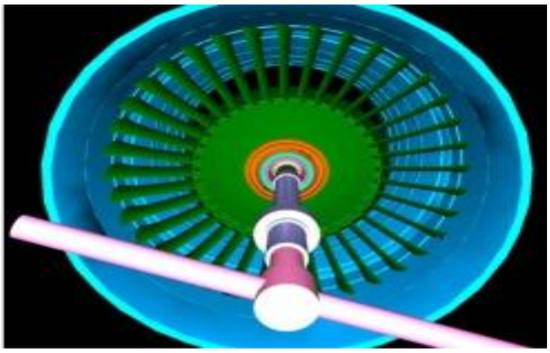
1)Hardware of Dental Surgery Simulation System:



Hardware of Dental Surgery Simulation System, and graphical scenarios of three typical dental operations, including dental inspection, periodontal depth probing, and implant surgery. The goal of the simulation system is to simulate the physical contacts between dental instruments and diverse tissues including teeth, gingiva, tongue and diverse pathological changes such as calculus and decay. The stiffness and friction coefficient difference between these tissues can be simulated and provide force feedback on the stylus of the haptic device, and the system can be used to train the fine motor skill of trainees, along with hand-eye coordination skill. The system include two force feedback devices, a half-silvered mirror system to provide visual-haptic collocation display, a supporting rest for fingertip, and foot pedal. The system can simulate typical dental surgeries including periodontal surgery, dental preparation surgery, and implant surgery.

2)Haptic Interaction System for Simulating Mechanical Assembly of an Air Craft Engine:





Above figure shows the Haptic Interaction system for simulating mechanical assembly of an air craft engine. The user is controlling the haptic device to insert a splined shaft into a splined hole. Force and torque feedback can be produced to simulate the tight clearance during the assembly process. As the hole is deep and the clearance is small, the quality of the assembly totally rely on haptic sensation.

Conclusion:

In conclusion, the world of Virtual Reality (VR) has been forever transformed by the introduction of haptic displays. These innovative technologies have ushered in a new era of immersive digital experiences, allowing users to not only see and hear but also touch and feel the virtual worlds they inhabit.

Our exploration of haptic displays in VR has taken us on a journey through the fundamentals of haptic feedback, unveiling the intricate mechanisms that enable users to interact with virtual environments on a tactile level. We've discovered the diversity of haptic feedback, including tactile sensations, kinesthetic feedback, and force feedback, and have witnessed how each type contributes to a heightened sense of presence and realism in VR