Haptic Integration in Virtual Reality

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Introduction

Traditional and current virtual reality is naturally most concerned with the visual percept: what people perceive when they see, how they perceive it, and how to exploit that perception in order to expand the limits of what virtual reality is capable of portraying and displaying. There is no doubt that vison is a significant percept, and much of virtual reality's strengths lie in how it can use that percept. However, there is only so much one sense can successfully convey by itself, and in order for virtual reality to become more immersive, other senses need to be incorporated into a multisensory virtual environment. Audio, which like vision is externally focused, is relatively easy to add (and has been largely incorporated); the haptic percept, however, is more difficult. Haptics, or the sense of touch, is challenging to incorporate with current technology because the goal of virtual reality in most cases is to immerse the user in a virtual environment entirely disparate from their physical surroundings. The most basic way to incorporate haptics—creating a one-to-one physical replication with which the user can interact tactically—is not only impossible most of the time but also contradicts the goal of virtual reality. A level of sensory manipulation and consideration is needed for haptic integration that is unnecessary for the visual or audio percepts, accomplished through a variety of means, including pseudo-haptics and redirected touching. This review looks briefly at the literature and research concerning haptic integration in virtual reality, both in terms of necessary background information—how the human brain processes external signals—and means of integration, in order to demonstrate the current state of haptic integration and how that state may be improved upon.

Sensory Perception and Integration

Because the goal of virtual reality is to create entirely new and immersive environments, it is necessary to understand how the human brain receives and processes information from the external world. It is especially important to understand how different percepts—especially haptics and vision—work together to form an understanding of a person's surroundings. The human brain at any given time has multiple senses relaying information about a person's surroundings, all of which must be efficiently combined and processed to form a complete mental picture of the environment. In many cases, visual perception dominates over the other senses, a phenomenon called "visual dominance" or "visual capture". Ernst and Bültoff [1] review visual capture and sensory integration, citing multiple sources showing that, in the case of discrepancies between the visual and haptic percepts, the visual frequently dominates. However, they note that vision does not always dominate, citing Wench and Warren's "Modality Appropriateness" hypothesis: in the case of discrepancies between senses, the most appropriate sense for the task is taken most seriously. For spatial tasks, such as judging size, scale, or distance, vision is usually best suited; but recognizing texture, for example, is better suited for haptics.

While studying what the brain perceives is relatively easy via user studies and other experiments, *how* the brain processes sensory input is quite a different matter. There is no way to directly test how the brain processes information from various senses; the best way to examine the brain's, for lack of better term, thought process is to compare results from studies to expected results from "ideal observer" models, such as a Bayesian model. Ernst and Banks [2] used this method of comparison with a maximum-likelihood integrator to demonstrate that visual-haptic information is combined in a "statistically optimal fashion", where the dominating sense (either vision or haptics) is determined by which sense has the lower variance associated with it. In other words, the sense that dominates between vision and haptics depends on which sense is deemed more appropriate by context and input.

Of course, vision and haptics are not the only senses at play in virtual reality. Proprioception, the body's ability to sense where body parts are in relation to itself, must also be considered as actions and any visual representation of the user's self must match the user's sense of their own position and movement. van Beers, Sittig, and Denier van der Gon [3] show that, when proprioception and vision are combined, the brain weighs the two senses in a direction-dependent manner, so the most weight is afforded to the more accurate or appropriate sense in a manner similar to vision and haptics. While vision tends to dominate both combined inputs, proprioception and haptics can and will dominate in cases—and, of course, the disparity between the two senses cannot be too large, or the brain will notice the conflicting sensory inputs.

With current technology, however, a faithful and well-tracked avatar requires much calibration and tracking; tracking is instead often limited to the head. This severely limits the amount of embodiment possible in many virtual environments. The lack of visual embodiment leads to spatial delocation, where the tactile and proprioceptive sensations associated with a particular task—for instance, rotating a handle [4]—are physically separated from the visuals. Congedo, Lécuyer, and Gentaz found that, in a fish-tank virtual environment, subjects relied almost exclusively on vision to rotate a hidden handle whose visuals were relayed via a computer-generated model on a monitor [4]. Current virtual reality technology benefits from the phenomenon of spatial delocation: the lack of embodiment skews perception towards vision and makes simple haptic integration more feasible. Adding embodiment could help unify the senses and increase immersiveness, but it could also make haptic integration more complicated as visual dominance decreases and the senses are evaluated more equally.

Integrating Haptics into Virtual Reality

Even if one ignores the accuracy and efficiency of human perception, integrating haptics into virtual reality is a complicated matter. Traditional game and computer systems already frequently involve a small level of haptic integration, commonly through vibration feedback in the controller. The appeal of virtual reality, though, is its total freedom and immersiveness—one is not limited to a computer or television screen with a connected controller. If an environment can be rendered, one may be immersed inside it with virtual reality. A controller is, ideally, unnecessary, because gripping a controller or joystick would take away from the immersive quality of virtual reality (unless, of course, one is driving a car, flying a plane, or performing some similar task within the environment). In addition, haptic integration in virtual reality would ideally go further than basic vibration feedback, including torque and other force feedback as well as sensations such as shape, size, and weight of objects. The challenge of haptic integration, then, is that the physical world is not nearly as versatile as the virtual one. It is simply not possible at this time for a tactile object to be as infinitely customizable and changeable as the virtual environment it would mean to support. Haptic integration necessarily relies on sensory manipulation and illusions in order to achieve any level of versatility.

The most basic form of haptic integration in a virtual environment is, of course, creating a one-to-one physical model of the virtual environment. Called passive haptics, this method by itself has little to no flexibility: a physical plane cockpit, for example, will always look and feel the same without involved (and possibly costly) modification, while the virtual model of the same cockpit can change drastically (with the proper programming) with the touch of a button. Kohli [5] proposes making these passive haptics more flexible by mapping multiple virtual objects to one physical one by warping the space inside the virtual environment. Kohli calls this redirected touching [5], as the illusion causes the user's avatar hand to move within the virtual environment differently than the user's actual hand, done in such a manner that the virtual and physical hands touch an object at the same time. In this way a single physical object—to continue the example, a cockpit—could be used to represent many different cockpits. Ban, Narumi, Tanikawa, & Hirose [6] [7] propose a similar technique with smaller objects: their physical object is a small cylinder with a moveable raised ridge instead of a whole cockpit, but both techniques map many virtual objects onto one physical object using space warping and visual displacement of the user's hand.

There are limits to these techniques, however: Kohli's work in [5] is preliminary and only works on planar surfaces, and both Kohli's and Ban, Narumi, Tanikawa, & Hirose's works work best with point interaction [5] [6] [7]. Neither work allows for extended interaction or exploration of an object or set. In addition, of course, the set or object can only be used for so many related objects. A car dashboard could not be easily mapped to a cockpit set, for instance, and a cube cannot be mapped to a cylinder with an angular bump. Car dashboards, cubes, and all other unrelated objects and sets would require their own mappable sets and objects.

Given the difficulties in creating a physical object capable of even barely keeping up with the versatility of virtual reality, another avenue of haptic integration, pseudo-haptics, seeks to do away with physical objects as much as possible. Pseudo-haptics instead focuses entirely on sensory illusion to give the user the *impression* they are touching or otherwise physically interacting with something. Using visual dominance and the integration of the senses, pseudo-haptics conveys to the user such properties such as the stiffness of an object by altering how the virtual, visible object appears to respond to user input or actions [8]. Pusch and Lécuyer describe the general design principles of pseudo-haptics in [8]; by manipulating the appearance of objects, they explain, a virtual environment can give a user the feeling that, for instance, a virtual spring is getting harder and harder to compress. By using either a basic haptic device or no haptic device at all, pseudo-haptics greatly increases the flexibility of haptic integration.

However, like passive haptics and redirected touching, pseudo-haptics has limits. It works best with cause-and-effect: press down on a haptic device and a spring or piston compresses [8]. Move one's hand towards a visible "force field" in the environment and watch one's hand appear to meet resistance as drift in the video causes one to "correct" the course of one's hand [8]. Exploring objects with one's hands or picking up objects and moving them around is, in most cases, currently not possible with pseudo-haptics, because there is no physical object to explore or move.

Summary

Virtual reality is, by its nature, very vision-focused. In order to make virtual environments more immersive, other sensory percepts such as haptics need to be incorporated into these environments. This incorporation requires understanding of sensory integration and combination and how the brain resolves sensory conflicts. While formulas have been developed formalizing the way in which the human brain processes sensory information, relatively little is still known about the process, or the limits of sensory combination in cases of conflicting sensory input. For haptic integration, which relies on a certain level of sensory manipulation, empirical knowledge of these limits is necessary in order to successfully bring full haptic perception into virtual reality. Current haptic perception in virtual reality is fairly limited, working best with point interaction between the user's hand and the touched object. Kohli [5] and Ban, Narumi, Tanikawa, & Hirose [6] [7] both use physical objects whose appearance in virtual reality has been manipulated; pseudo-haptics as explained by Pusch and Lécuyer [8] moves away from actual physical objects to almost pure sensory illusion. Both techniques rely on the phenomenon known as visual capture or visual dominance to operate. While both approaches are fairly flexible, neither are currently nearly as flexible as virtual reality.

The challenge in incorporating haptics into virtual reality is that the physical, tactile world is not nearly as versatile or immediately changeable as virtual reality currently is. Pseudo-haptics and redirected touching give a certain level of flexibility to haptics, but both are currently limited in ways virtual reality simply is not. Haptic integration will need to be further researched, developed, and innovated upon as virtual reality continues to expand, and as more is known about the ways in which the brain processes multisensory information.

References

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