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Resumen de Paper *Tapping with a Handheld Stick in VR: Redirection Detection Thresholds for Passive Haptic Feedback*

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1 Introduction

The term haptic is related to touch. It is well-known that the sense of touch is one of the main mechanisms humans have to interact with their surrounding environment. Therefore, we can take advantage of haptic feedback to increase the sense of realism in a VR experience. The reference material explores the possibility of “touching” virtual objects with a handled stick. Although vision and hearing are the main factors to consider for immersive experiences, they are not enough, therefore haptic feedback becomes a great help to trick the brain into thinking it is indeed inside the simulation.

It is important to notice that other techniques for haptic feedback have already been used in the past like gloves, pens suits and vibrating controllers. These all share the characteristic that they mimic a haptic stimulus. On the other hand, the proposed solution of the stick is of grounded passive nature which relies on real objects and matching the contact with it in the VR scene.

The challenge is that real objects do not always match the VR objects. A technique used to reduce this discrepancy is *redirection*. This consists in changing the direction of movement of the user or objects to match the real ones and their virtual counterpart. For example, the hand of the user can be redirected, or a virtual chair can be repositioned.

You may be wondering, why to give the haptic signals by a stick and not directly through the user's hand. The researchers had two main reasons. The first one is that many applications may need a stick (or something similar) as the main interaction method, for example, a sword simulation. The second one is that the stick has more indirection levels, a factor that can be used as great haptic feedback.

When touching something with your hands you are expecting a great level of sensory detail as the size, shape, or texture of the object, which is difficult to recreate with VR. Nevertheless, with a stick, the haptic expectations reduce drastically, making a believable recreation in VR easier. Additionally, touching with a stick is less precise, this helps the *redirecting* technique.

To implement the stick, the authors proposed two methods. The first one was *DriftingHand.* This alters the virtual hand position and consequently the virtual stick´s position. The second method, called *VariStick,* this one changes the orientation and length of the virtual stick. Both approaches have the goal to synchronize the haptic feedback with the real-world contact.

An experiment with 60 participants was conducted. The users had in front a real whiteboard that provided that haptic feedback. The users had to “touch” with a stick some virtual spheres that were “placed” in front and behind the whiteboard. The participant had to touch two spheres, one of those was redirected. Then the participant had to tell, in their opinion, which of the spheres was the one that had the redirection applied.

2. Prior work

To have a better understanding of this investigation, it is convenient to contextualize with related work. The term active haptics refers to the use of VR system trigger actuators that contact the user. These assets usually are wearable, this characteristic gives them a bigger range of motion, but they also tend to be intrusive. Additionally, these garments have a limited resolution of stimuli.

2.1 Active and mixed haptics

An example of these advances is the Benko NormalTouch controller that gives feedback shape and surface structure. Another example, the PHANTOM haptic system that allows the user to feel forces. It also mimics surface bumps and rugosity.

The example given shares the limitation of lack of versatility. Usually, these elements have a very limited catalog of options to “transform” into. The authors propose to make the haptic object part of the narrative, to avoid the awkward feeling of always feeling it even though you are not using it at that moment in the VR experience.

2.2 Passive Haptics

Passive haptics is the other stream found in this area of study. In this case the real object that provides feedback is stationary. For the user to get the haptic feedback, the virtual and real object need to be aligned. Notice the simplicity of this approach. This technique works better for a one-to-one mapping between the real world and the virtual objects.

Due to the fact that virtual and real objects must be aligned, it is difficult to find an opportunity to send haptic feedback. These are possible solutions. Try to make the virtual world to match the real space. Or design physical objects to cover most of the virtual objects that send haptic feedback. Also, there is the possibility to use redirection.

The challenge with redirection is to make it unnoticeable to the user. There are factors like the sensibility of the tool used to touch (a stick or the hand), or the discrepancy of movement between the real and virtual objects. Another example is to extend the redirection. The milliseconds meanwhile the user is blinking can be used to make the redirection without the user noticing it.

The researchers explore redirection with sticks of various lengths. Also, the study the influence of the real-world distance between the user and the objectos. They also mention that distance is proportionally inverse to the acuity of perception.

3. Redirection for the passive haptic feedback when tapping with a handheld stick in VR

For the illusion the contact of the objects in the real and virtual world have to be synchronized, which limits the passive haptic feedback to the instances when the two geometries match. One option is to move the virtual object to match the real-world object.

If the user relies on a handheld stick, redirection for passive haptic feedback might be easier to hide. They developed 2 passive haptic feedback methods designed specifically for the handheld stick VR interaction scenario. One that redirects the stick together with the user hand, and another that concentrates the manipulation at the tip of the stick.

3.1 The DriftingHand redirection method

The DriftingHand method, alters the position of the visual hand to realize that the tip of the virtual stick makes contact with the virtual object at the same time the tip of the real stick does with the real object. The methot keeps the virtual stick parallel to the real one. The redirection is applied as a translation of the virtual hand of the user and the virtual stick, forward or backward.

- **Beginning of redirection:** When the tip of the stick gets within a horizontal distance of the virtual object, and there is a real-world object, redirection begins. If the distance is negative the virtual object is farther from the user than the real-world object. If the distance is positive the virtual object is closer to the user than the real-world object. If there is no real-world object sufficiently close, there is no redirection, and the virtual contact occurs without passive haptic feedback.
- **During redirection:** While the distance d_r between S_r and W is less than the initial distance when redirection began, the virtual hand is offset by the real one.The variables will change to reduce all the distances to 0.
- **Contact:** When S_r reaches W, both d_r and d_v are 0, so the real and virtual contacts occur simultaneously.

ε_{max} is the maximum distance between the virtual and real objects.

d_{r0} is the distance between the tip of the real stick and the real wall when redirection begins.

ε is known based on the known real and virtual object positions.

This method shifts the user's focus from their hand to the tip of the stick. However, the position of the tip of the stick is rigidly coupled to that, so it inherits the position alterations applied to the virtual hand, which are in contradiction with the user's proprioception.

3.2 The VariStick redirection method

VariStick alters the length and the orientation of the virtual stick, doing that the tip of the virtual stick makes contact with the virtual object at the same time the real ones do. The tip of the virtual stick is translated forward to reach the virtual object which is farther than the real-world object. The virtual hand is kept in place. If the virtual object is closer than the real object the virtual stick is scaled down to reduce its length.

The translation of the tip of the virtual stick is the same as the virtual hand in the *DriftingHand* method. The length of the stick is computed as the distance between the user's hand and S_v, which puts the tip of the virtual stick at the desired location while keeping the virtual hand in place.

Like the *DriftingHand* method, the *VariStick* method also uses the stick to shift the user's focus away from their hand. But *VariStick* also alters the position of the tip of the virtual stick to achieve virtual contact without moving the virtual object and keeps the virtual hand in place. The redirection is introduced gradually, from the grip to the tip of the stick, through scaling, potentially avoiding a proprioception conflict.

4. Evaluation

The goal is to evaluate the *DriftingHand* and the *VariStick* redirection methods for haptic feedback for virtual to real object distances without the user noticing.

4.1 Experimental design framework

According to psycho-physics research, thresholds should be measured with a forced choice experimental design in which the participant has to choose between the stimulus levels 0 and the higher level selected by them, this design is called two-alternative forced choice (2AFC). A variant of this design is called two-interval forced choice design (2IFC) which consists in presenting both alternatives in succession as a simultaneous event.

When a participant doesn't detect the level or can discern between the two, the accuracy is 50% called *point of subjective equivalence* (PSE). A goal of the psychometric research is to establish the threshold for the stimulus level above, the participant is expected to choose correctly and consistently. The threshold is determined by fitting a sigmoid psychometric function to the correct response rates over various stimuli levels and intersecting it with the 75% line.

The redirected walking (RDW) VR research based on 2AFC requires that the participant walks several times in the virtual environment in order to work. Instead, RDW detection threshold research relies on a simpler 2AFC in which the participant has to walk in the environment just once and is just presented with one stimuli level, this is called pseudo-2AFC design.

Another aspect of the experimental design is whether to use fixed stimuli levels which provide the threshold value and shape of the detection rate as a function of stimulus level and can be more accurate or to adapt the stimulus level based on the participant's previous responses which results in fewer trials.

4.2 User study

The distance offset detection thresholds for the two passive haptic redirection methods were investigated.

- **Participants:** 60 participants between the ages of 19 and 30 of a university, 15 female. 12 participants with no experience with VR, 15 used VR once, 29 used VR occasionally and 4 used VR frequently.
- **Experimental setup:** Each participant was asked to stand in front of a whiteboard wearing the VR headset and holding the controller with a somewhat elastic bamboo stick attached.
- **Procedure:** A 2IFC design was used. For each trial, the participant was shown two virtual spheres, one at the time, at the height of the participant's head and in front of the stick. There was no distance between the first sphere and the real object providing the feedback, the second sphere was offset with respect to the whiteboard plane which had to be bridge by the haptic redirection methods.

  For each trial, the offset of the sphere with redirection was counterbalanced from the set {-100cm, -75cm, -50cm, -25cm, -10cm, 0cm, 10cm, 20cm, 30cm} with negative being behind the whiteboard, for the other sphere ε = 0cm. The trials were grouped in blocks of 27 trials, with each of the 9 epsilon values being used exactly three times. The colors and dimensions of both spheres changed in each trial in order to avoid the participants learning the pattern.

  The participant was asked to hit each sphere with the stick, when contact was made, the sphere moved away from the user in a velocity proportional to the speed of the stick. Participants received haptic feedback from the whiteboard whose collision with the real stick was synchronized with the virtual one using the two redirection methods.

  After the second sphere was hit, the questions were displayed "For which sphere did the virtual stick change in length?" for the VariStick method and "For which sphere did your virtual hand NOT move as expected?" for the DriftingHand method. The participants had to choose one of the spheres in order to continue.

- **Dependent variables:** Each block of trial measured two detection thresholds in cm: *τf* for the threshold with the virtual object farther and behind the real one and *τn* for the threshold with the virtual object closer and in front of the real one.
- **Independent variables:** *τf* and *τn* were measured for 24 conditions: 2 haptic redirection methods * 4 stick lengths * 3 distances between the user and the whiteboard.
- **Data collection:** Each participant used only one stick length and had a training session at the beginning. The participants were told to perform 6 blocks of 27 trials, the experimental session took at most 27 mins.
- **Data analysis:** The detection threshold *τf* and *τn* were estimated for each of the 24 condition combinations using a psychometric function.
- **Discussion:** For the VariStick method, the smallest *τf* and *τn* are 20 cm and 13 cm, meaning that no matter the stick length and the whiteboard distance, participants were unlikely to detect redirections in the ε interval of [-20cm, 13cm]. For the DriftingHand method, the interval was [-11cm, 11cm], overall VariStick hides haptic redirection better. *τf* also tends to be larger than *τn* in both methods. For VariStick, the thresholds tend to increase with stick length, confirming the hypothesis that the farther the point of contact is away from the end of the user's hand, the less the user can discern the redirection with the exception of the shortest stick and the farthest whiteboard. For DriftingHand, the threshold does not increase with distance. VariStick also has significantly larger detection thresholds compared to DriftingHand.

5. Conclusions, limitations and future work

Two redirection methods for passive haptic feedback when touching objects with a stick while using a VR application were studied: Varistick and DriftingHand. Varistick provides more passive haptic opportunities within the range of -20cm and + 13cm. DriftingHand provided -11 and +11. The user is likely less aware of the stick length and orientation than of the position of their hand. Varistick ignores user hand position.

DriftingHand manipulates it to increase presence in the virtual world. Hybrid approaches should be researched.

The study was designed to cover a large number of variables: stick length, wall distance and method. Future work could extend the study with increased repetitions and fewer independent variables.

Prior work measured hand redirection detection between -3.5cm and 6cm. Therefore the stick extends the users' detection thresholds compared to the hand.

Since the study was a repetitive experiment which may disengage participants, mechanical answers may become a factor. A proposed solution was to introduce rewarding elements like sound along with the associated risks as noise in the measurements.

Vertical plane was used. Future studies could use other orientations.

This work detected thresholds in the z axis (user view direction). More work is needed in the y (up and down) and x (left and right) axis.

Future work can rely on the measurements to create narratives that include a stick.

Authors suggest using the stick as something else, like a laser pointer but keeping the haptic feedback.

Finally, the authors of this paper propose studying VR props further so they feel right depending on their weight.

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