

# Exploring the Perception of Co-Location Errors during Tool Interaction in Visuo-Haptic Augmented Reality

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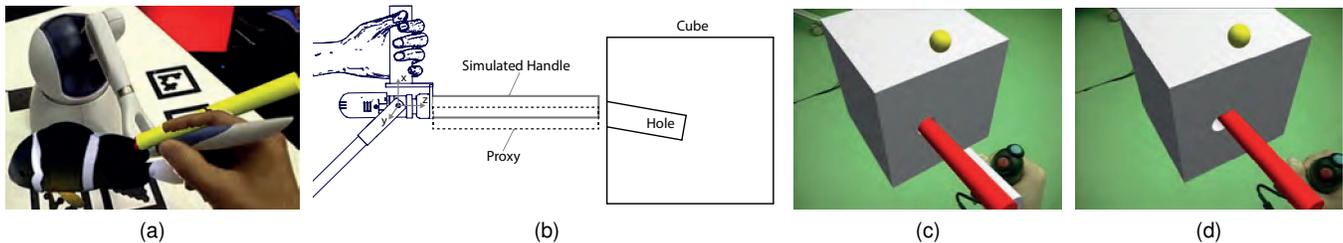


Figure 1: When integrating haptic devices into Augmented Reality systems, alignment errors are unavoidable; (a) example [4]: note how the haptic device handle (pen in user's hand) and its virtual representation (yellow/red pen), or proxy, are misaligned. In this poster, we investigate human perception of such misalignments through a peg-in-the-hole task: in order to fully control errors, we simulate the device handle and the proxy (b), which allows us to vary the alignment error from zero to any higher value. We study two possible interaction modes: (c) augmenting a virtual tool (red) at the proxy pose over the handle (white) and (d) using a real tool (red) with hidden proxy.

## ABSTRACT

Co-located haptic feedback in mixed and augmented reality environments can improve realism and user performance, but it also requires careful system design and calibration. In this poster, we determine the thresholds for perceiving co-location errors through two psychophysics experiments in a typical fine-motor manipulation task. In these experiments we simulate the two fundamental ways of implementing VHAR systems: first, attaching a real tool; second, augmenting a virtual tool. We determined the just-noticeable co-location errors for position and orientation in both experiments and found that users are significantly more sensitive to co-location errors with virtual tools. Our overall findings are useful for designing visuo-haptic augmented reality workspaces and calibration procedures.

**Index Terms:** H.5.1 [Information Interfaces And Presentation]: Multimedia Information Systems—Artificial, augmented and virtual realities

## 1 INTRODUCTION

Visuo-haptic augmented reality (VHAR) user interfaces enable users to see and touch digital information that is embedded in the

real world. The goal of such user interfaces is to provide realistic force feedback when user operated handles are in contact with virtual objects that are embedded in the real environment. Visual and haptic feedback are co-located if users perceive their interaction as consistent in their visual and kinesthetic input channels. Operators need to carefully calibrate VHAR environments to achieve accurate co-location of vision and touch. Such calibration requires time and must be repeated on a regular basis.

Interaction handles of haptic devices are often represented as tools like a pen for drawing (see Figure 1a), a scalpel or syringe for medical procedures, or hand tools for assembly planning and verification. There are two fundamental ways of integrating tools into VHAR systems: *Real* tools are physical objects that are rigidly mounted to a haptic device. *Virtual* tools are represented as augmentations over the haptic handle. Both methods of integrating tools are viable alternatives when designing VHAR applications, but it remains unclear how users perceive errors between visual and haptic stimuli when using real or virtual tools.

Lee *et al.* [3] studied the effects of registration accuracy between visual and haptic feedback during a target acquisition task. Their results show that spatial registration errors have a significant effect on the accuracy of the targeting task. Registration errors however have no effect on movement time. They also found that with increased stiffness of the rendered surface, users would rely more on haptic than on visual feedback. Barbieri *et al.* [1] studied the effects of misalignment during force application on the perceived naturalness as part of their evaluation. Their participants did not perceive the improved co-location condition as more natural, although they performed better in it.

When integrating haptic devices into augmented reality systems, alignment errors are unavoidable. Users can see such alignment errors if virtual tools are incorrectly augmented over the haptic handle (see Figure 1a), if real and virtual objects unnaturally intersect dur-

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ing contact, or if forces are displayed without visual contact. In this poster, we investigate human perception of such misalignments through a peg-in-the-hole task. To fully control errors, we simulate the haptic handle as a virtual peg, which allows us to vary the alignment error from zero to any higher value (see Figure 1b). The resulting thresholds will be useful to minimize the required effort for workspace calibration and as guideline for designing VHAR environments.

The contributions of this poster are twofold. First, we determined just-noticeable co-location errors, which can be used as guides for VHAR system designers and operators. Second, we showed that workspaces with virtual tools should be calibrated more accurately than workspaces that use real tools.

## 2 EXPERIMENTAL DESIGN

In two experiments we simulate the effects of co-location errors for real (E1) and virtual (E2) tools and measure the just-noticeable position (C1) and orientation (C2) errors using a two-interval forced choice design. We simulate the co-location artifacts using two virtual cylinders (see Figure 1b). The first cylinder represents the simulated device handle (HANDLE) and is rigidly attached to the haptic device as extension to the users arm. The second cylinder represents a collision proxy (PROXY), which is controlled by physics-based simulation and used for haptic rendering. Co-located setups are simulated by attaching PROXY at the exact pose of HANDLE. Degenerated setups are simulated by either adding position or orientation errors to the pose of HANDLE before attaching PROXY (see Figure 1b).

We simulate the real tool scenario by visually rendering a red peg representing the tool (HANDLE) and hiding PROXY (see Figure 1d). In the virtual tool scenario we render a white peg (HANDLE) in the background to simulate the haptic device handle and a red peg to represent the augmented virtual tool, which coincides with PROXY (see Figure 1c). The incorrect occlusions for the second scenario closely resemble the effects of co-location errors in video see-through augmented reality when using virtual tools (see Figure 1a).

Participants perform two consecutive peg-in-the-hole tasks per task unit and then decide which one has the larger co-location error. We study two conditions: C1 a randomly chosen task contained a position error, and C2 a randomly chosen task contained an orientation error. We control the co-location error using a staircase procedure with a minimum of ten reversals and record the users decisions along with their stimuli.

**Independent Variables:** We varied the co-location accuracy by adding a position error or an orientation error to the attachment transform of the haptic shape that represents the peg. Feasible values for the initial stimuli and the step sizes were identified during pilot studies. To limit learning effects, we changed the direction of the error randomly.

**Dependent Variables:** We recorded the users' answers along with the presented stimuli to calculate the just-noticeable co-location errors.

## 3 EXPERIMENTAL PLATFORM

Our setup consists of a HAPTION Scale1 room-size haptic device, a Natural Point Optitrack tracking system, and a Canon VH-2002 head mounted display. We implemented our VHAR application using the Ubitrack tracking and sensor-fusion framework and the HAPTION IPSI simulation and haptic rendering server. We adapted the workspace calibration method proposed by Eck *et al.* [2] to spatially and temporally co-locate the haptic device.

## 4 RESULTS

We performed both experiments at the same time with ten participants ( $25 \pm 2$  years) that randomly started either with the real tool

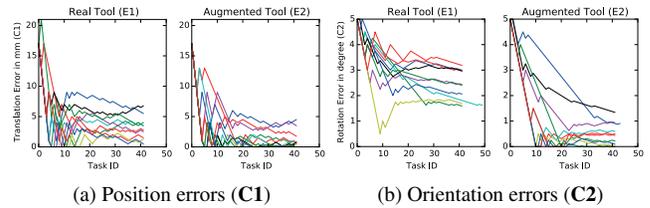


Figure 2: Trace of staircase procedure for all users in both experiments: Real Tool (E1), Augmented Tool (E2) and two conditions.

	Real Tool	Virtual Tool
$\bar{k}_t$	$3.56 \pm 1.90mm$	$1.36 \pm 1.42mm$
$\min k_t$	$1.23mm$	$0.1mm$
$\bar{k}_r$	$2.66 \pm 0.63^\circ$	$0.69 \pm 0.72^\circ$
$\min k_r$	$1.68^\circ$	$0.01^\circ$

Table 1: Resulting just-noticeable co-location errors ( $k_t$  for C1,  $k_r$  for C2) for both experiments.

(E1) or the virtual tool (E2) experiment. The ordering of conditions C1 and C2 within an experiment was randomized. Eight participants did both experiments. During an introduction session, participants were able to try the system and were shown examples of co-location errors with translation and rotation offsets. The duration of a trial was approximately 30 minutes.

The recorded stimuli during the staircase procedure for both experiments are shown in Figure 2. At the end of each procedure the just-noticeable error was computed as the mean of the stimuli that were displayed at the last eight reversal points. The final values  $k_t$  for C1 and  $k_r$  for C2 were calculated as the mean for all participants for each condition (see Table 1). The results show a clear trend towards thresholds for perceiving position errors and orientation errors. The eight participants who did both experiments were significantly more sensitive to co-location errors in E2 (Kruskal-Wallis test results: C1  $p < 0.027$ ,  $d = 1.23$ ; C2  $p < 0.033$ ,  $d = 2.62$ ) than in E1.

## 5 CONCLUSIONS AND FUTURE WORK

In this poster, we presented the design and results of two experiments that we performed to determine the just-noticeable co-location errors in VHAR systems with tools. The results show that users are significantly more sensitive to co-location errors when using virtual tools than with real tools. In future work we plan to study scenarios with a physical peg attached to the haptic device in combination with state-of-the-art occlusion handling in order to further explore the feasibility of using real tools in visuo-haptic augmented reality systems.

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