Quantifying Industrial Touch: Taking a Task Performance Approach To Quantify Feedback Modality Contributions to VR Manufacturing Training

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***Abstract*— An integral part of creating compelling and useful immersive virtual environments is the presence of haptic feedback, where both kinesthetic and cutaneous feedback convey unique information critical to object handling and manipulation. The benefits of tactile rendering for collisions and forces during virtual and telemanipulation are well documented in the literature. However, the default metric for assessing system performance – task-completion-time – offers limited insight into the mechanisms underlying human behavior captured in task performance. It offers incomplete information as to where, when, and why temporal differences occur between haptic feedback conditions.**

We aim to identify improvements made by the addition of haptic feedback to a haptic glove, through isolating the contribution of event-based vibrotactile feedback and resistive force-feedback. By applying a hierarchical task-analysis approach, rather than focusing on completion time alone, we are able to quantify participants' behavior in time and space. The approach allows us to explore the differences between expected physical world behavior and corresponding behavior in a virtual environment. To determine if our application of a hierarchical task-analysis method provides insights into human behavior at a mechanism level, we perform an analysis of a simplified industrial task in virtual reality.

In this work, we outline our approach, and contrast it against current standard methodologies. We discuss the strengths and limitations of both the task completion time and the dynamic behavioral task metrics as well as present preliminary results.

***Index Terms* - Tactile Feedback, Vibrotactile Feedback, Un-Grounded haptic device, Haptic Feedback, Grasping, Virtual Reality, Virtual Reality Gloves, Haptic Gloves**

I. Introduction

Task-completion-time(TCT), the time it takes for a participant to complete a task, is often used as a metric to determine performance rate of haptic devices in assembly tasks [2] [4] [3]. A valid metric for the assembly industry where time is money, as well as it is a good representation of task complexity and the executors performance level. However, tracking time by itself offers limited insight into the behavior required for task execution. This extra layer of insight, by capturing skill-based behavior metrics, has been proven valuable for identifying bottlenecks within teleoperated assembly tasks [1]. Our study is inspired by this approach such that, next to TCT, we study human behavior characteristics in order to analyse the effects of different haptic feedback modalities on task execution.

II. Method

[1] Stimuli: Force Feedback was provided by a SenseGlove Developer Kit (DK 1.3), that incorporates 1-DOF resistive kinesthetic feedback utilizing a friction plate and armature. The feedback can provide 18N of force on each fingertip. Grasped objects were treated as fully solid (18N). The L5 Actuator by Lofelt, a Voice Coil, was added on the index finger and the thumb to provide the Vibrotactile Feedback. The L5 was controlled by a Teensy 4.0 microcontroller supplemented by an Audio Adapter board. Vibrotactile feedback was fired upon contact events by the fingers or grasped objects. The feedback model was based on an event-based haptic approach and obtained from a database of decaying sinusoids stored on an SD-card[[5]]. The virtual environment was developed in Unity by SenseGlove. It was displayed through an HTC Vive Pro headset.

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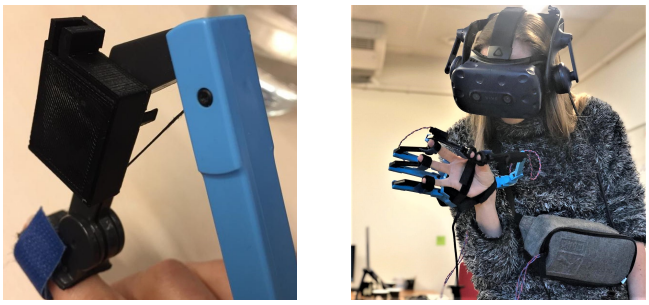


Actuator Container — The fannypack set-up

Fig. 1: a) The actuators are contained within a 3d printed box and screwed to the exoskeleton arms. b) The controller is contained in a fannypack-worn around the waist.

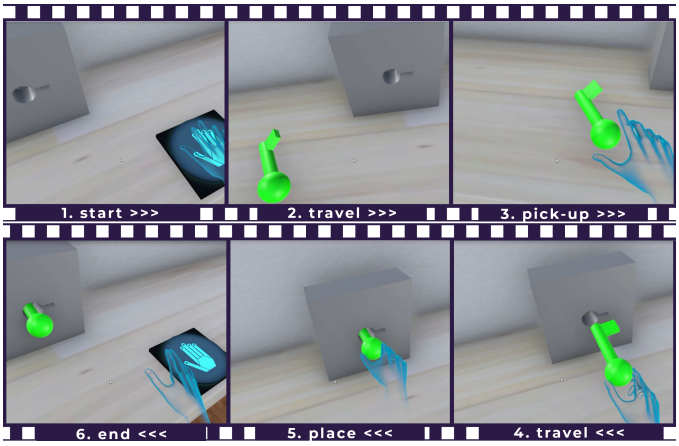


Fig. 2: Pick-and-Place task scene

[2] Task: Subjects acclimated with a five-minute' free play without haptic feedback. After familiarization, five trials for each four conditions in random order are looped through as a training phase. During each condition, the task is to pick up a key and place it into a socket, without breaking the key. After the training phase, subjects are asked to perform fifteen trials for each four conditions.

[3] Key Metric: While generic virtual controllers help learn the global operation steps, haptic gloves are used to train the fine motor control skills for assembly operations. The offered feedback, being visual and/or haptic, not only immerses subjects into the environment but also lets them experience how to handle delicate or tricky objects. By tracking the Finger Indentation,the distance that a fingertip travels into the virtual surface of the grasped object(Figure 3, we can capture the grasping realism for each condition. Finger Indentation should be close to zero during the force feedback condition, but it is also hypothesized to show that the vibrotactile feedback, that is only sensed during impact events, will have a lasting effect on the grasp form. Meaning, the participants will stop grasping through the virtual object and the Finger Indentation will therefore also be close to zero.

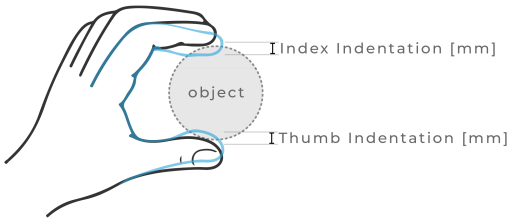


Fig. 3: Finger Indentation [mm] object.

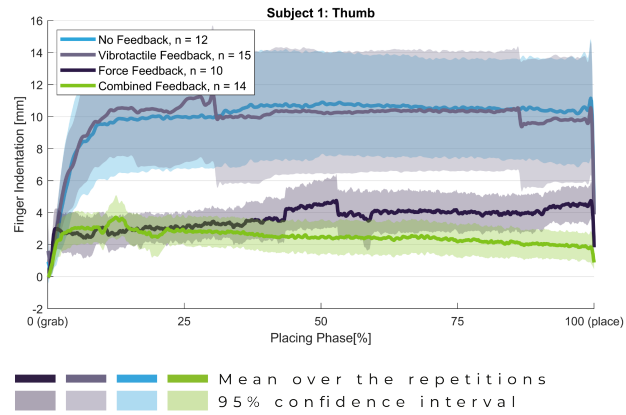
III. Results

We performed a user study (n=3) with right-handed participants. The initial results on task level suggest that the Task Completion Time does not improve due to haptic feedback modalities, compared to the visual-only condition. The median of the no-feedback condition lies underneath force-feedback condition for all subjects. It is likely that there is a difference between the conditions. This would mean that participants are able to execute the task faster in the no-feedback condition, than within the force-feedback condition.

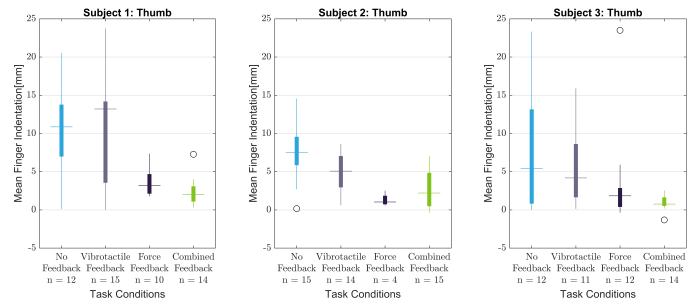
The initial results for participant one and two, showed that the thumb indentation was smaller when force feedback was present (either force feedback only, or combined force+vibrotactile feedback) than when force feedback was absent (no force feedback, or vibrotactile feedback only) seen in Figure 4b. For participant one and three the thumb indentation was smaller when vibrotactile feedback was added to force feedback (combined feedback) than any other condition. Meaning that when force feedback is supplemented with vibrotactile feedback, subjects will grasp objects with a smaller indentation compared to the other conditions. The initial results for the index finger indentation are less clear, but do seem to show a similar trend.

IV. Discussion

Visual Feedback is a dominant factor, and is a big part of the action-phase control system. Although this task is simple and the grasping and alignment subtasks are visual, the contact event of locking the key in place is not. The small overall TCT differences indicate that the visual modality is still key and might even be faster than the other conditions. Yet, being able to operate faster by working in a visual-only condition, might not be a preferable performance optimization for virtual assembly training. When realistic motor



(a)



(b)

Fig. 4 a) Thumb indentation of subject 1 from the moment of grabbing to the moment of placing, for four haptic feedback conditions. The mean over n repetitions is shown as the thick line, the shaded area depicts the standard deviation. b) The averages of each repetition, for all three subjects taken from 25% of the placing phase.

behavior is being diminished by the speedy movement, the operational muscle memory necessary for real-life operation is not being cultivated. The results from the dynamic behavioral metric, Finger Indentation, supports this theory. Without Force Feedback, subjects will likely grasp through objects at a larger distance and variability in Finger Indentation.

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