Vibrotactile feedback for collision awareness

C. Louison
Commissariat à l'Energie Atomique
Cadarache, 13115 France
+33 (0)442254088
cephise.louison@cea.fr

F. Ferlay
Commissariat à l'Energie Atomique
Cadarache, 13115 France
+33 (0)442252544
fabien.ferlay@cea.fr

D. Keller
Commissariat à l'Energie Atomique
Cadarache, 13115 France
+33 (0)442256104
delphine.keller@cea.fr

D. Mestre
Institut des Sciences du Mouvement, CRVM
Aix-Marseille University, 13288, France
+33 (0)491170438
daniel.mestre@univ-amu.fr

ABSTRACT
Magnetic Confinement Fusion machines called tokamak (e.g. ITER and WEST projects), as well as many industrial projects, require a high integration level in a confined volume. The feasibility of installation and maintenance by an operator has to be considered in the early stages of the design. Virtual reality technologies have opened new perspectives and solutions to take into account assembly and maintenance constraints, using virtual mock-ups. In our applications, the human factor takes an important role. Since the operator interacts in a very tight and confined environment, he has to pay attention to his whole body relative to the virtual environment, in the absence of haptic feedback. In this context, enriched sensorial information, called "collision awareness feedback", must be defined, to favour an appropriate operator's spatial behavior with respect to the environment. In this paper, we present a preliminary study, testing the effect of vibrotactile feedback in a simple tracking task, compared to a pure visual feedback.

Categories and Subject Descriptors
• Human-centered computing~Haptic devices • Computing methodologies~Interactive simulation • Computing methodologies~Virtual reality • *Computing methodologies~Real-time simulation* • Applied computing~Engineering

Keywords
Virtual Reality, Vibrotactile, Assembly Task, Collision Awareness, Tactile sense, Virtual Human.

1. INTRODUCTION
Virtual Reality (VR) has great potentials for assembly and maintenance tasks validation in industrial contexts. It allows considering the accessibility and feasibility problematics of assembly and maintenance in early stages of a design process. It has a very positive impact in terms of cost and time, e.g. by reducing the number of physical mock-up. However, if visual rendering of a complex confined space is nowadays satisfying, haptic rendering remains difficult if not impossible. This is a problem, since, to validate a maintenance task, the operator has to maneuver in a very tight and confined environment and to pay attention to his/her whole body and adopt a correct posture with respect to the environment (see Figure 1).

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2. APPROACH
While obtaining a force feedback is relatively straightforward using an haptic force device, these systems cannot be applied to all types of scenarios and are not satisfactory to interact with a complex Virtual Environment (VE), in particular when the whole body is involved. Two other interaction metaphors can be studied in this kind of environment: the addition of a tangible interface, such as physical elements within the user's workspace and lighter haptic systems for representation of localized information such as contact points, without restriction of mobility. This last metaphor can be implemented using vibrotactiles interfaces.

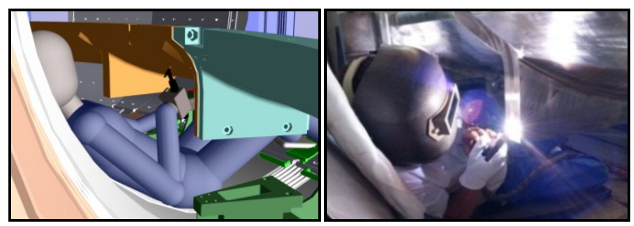

Figure 1. Welding task simulation in Virtual Reality and with a real mockup.

We propose to use vibrotactile feedback as a substitute for force feedback, to make users aware of impending or actual collisions in highly constrained spaces.

3. BACKGROUND
3.1 Vibrotactile and Collision Awareness
Vibrotactile devices have been used in a wide range of applications and contexts (e.g. [4]), including in "collision awareness" contexts with localized feedback. We would like to highlight three studies which have shown interesting results. Bloomfield and Badler [2] used vibrotactile cues to express collision in an exploration task. The subjects had to pass their arm (equipped with 24 vibrators) in a series of virtual puzzles. The results show significant collisions reduction with vibrotactile feedback, compared to a purely visual feedback. Lindeman et al. [3] studied vibrotactile feedback in several contexts. In one study, a jacket with 16 vibrators was used to improve the feeling of collisions in a VE. Yano et al. [5] created a 12 actuators array used to aid navigation in a virtual world. They showed that presentation of tactile clues was effective for imparting collision stimuli to the user's body.

4. EXPERIMENTAL STUDY

4.1 Protocol

The main hypothesis is that vibrotactile feedback leads to better movement precision in the environment.

We have designed a vibrotactile feedback prototype (see Figure 2), addressing up to 20 vibrators with 12 levels of amplitude, using Pulse-width modulation (PWM). Based on a microcontroller (ChipKit board) communicating via Bluetooth with a PC on which the simulation is running. The controller activates vibrators (DC motor with an eccentric mass) connected by wires.

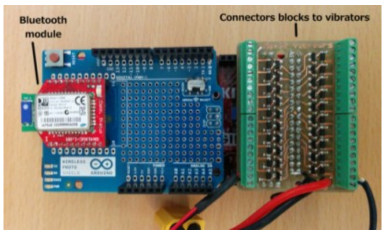

Figure 2. Vibrotactile controller prototype.

Six participants were recruited, to validate the prototype and evaluate different stimulation modalities. The evaluation involved a sliding task with the index on a (virtual) table edge, while avoiding collision with the table. A vibrator was fixed on the finger or the hand. The vibrator could signal collision (contact mode) and/or represent the distance to an obstacle (radar mode). This test took place in a four screens CAVE. Finger movements were tracked by an ART motion capture system (Figure 3).

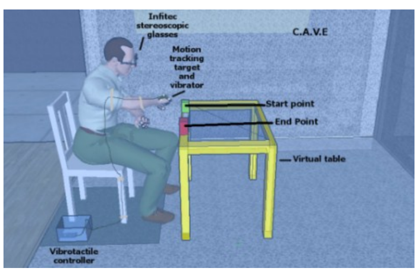

Figure 3. Experimental apparatus: The participant sits in the CAVE on a (real) chair, facing a virtual table. S/he wears tracked steroscopic glasses and his working hand, equipped with a vibrator, is tracked.

The independent variables were the type of collision-proximity feedback which included the "Contact", the "Radar" mode and a control case without vibrotactile feedback ("Visual" mode) and the position of the vibrator (Finger or Hand). Each subject carried out two sessions, one for each vibrator position. In each session, the type of feedback order was balanced between subjects. The dependent variable was the position of the finger relative to the table.

4.2 Results

Analyse of variance conducted on individual data (Root Mean Square Error –RMSE– pooled across trial repetitions) revealed a tendency ($p=.11$) to a difference in performance between feedback conditions and no difference between position conditions ($p>.4$). Post-Hoc analyses (Bonferroni test) revealed that "visual" feedback leaded to significantly higher scores ($p<.001$), compared to "contact" and "radar" feedback modes, and no difference between these last modes (Figure 4).

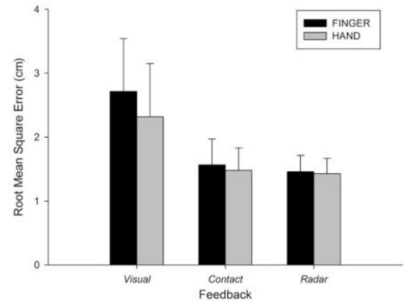

Figure 4. Average values of RMSE (with standard error) as a function of feedback and position of the device.

4.3 Discussion

The fact that there is no difference between hand and finger positioning of the device and no difference between radar and contact modes suggests that the vibrotactile feedback may act as an "awareness enhancer" for the task completion, rather than a precise mode on positional control. However, it remains to test, concerning the absence of improvement of the radar mode, compared to the contact mode, if we are not confronted here to a floor effect (in particular due to the resolution of the tracking system). Furthermore, we were dealing here with a simple tracking task (following a straight object). It remains to be tested whether these preliminary data extend to more complex environments, with multiple points of contact. We also propose to take advantage of the psychophysical phenomena called "funneling illusion" [1] to display perceptually continuous contact information.

5. ACKNOWLEDGMENTS

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