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HAPTIC INTERFACE TO INTERACT WITH A VIRTUAL VEHICLE COCKPIT

Fatima-Ezzahra DIRAA[1], Jean-Rémy CHARDONNET[1], Frédéric MERIENNE[1], Hamid HRIMECH[2]

[1]Arts et Métiers ParisTech, CNRS, Le2i, Institut Image
2 rue Thomas Dumorey, 71100 Chalon-sur-Saône, France
[2]Ecole Supérieure de Technologie de Berrechid, Université Hassan
Laboratoire d'analyse et modélisation de système pour l'aide à la décision-LAMSAD
Quartier Taqadom, Passage d'Alger, B.P : 218, Berrechid, Maroc

SUMMARY

This paper presents a device for interacting with a virtual cockpit of a vehicle with tactile feedback while driving. The design of this interface takes into account the criteria for virtual reality not inducing cognitive overload resulting from the complexity of use and the invasiveness of the device. Especial attention is taken to be as accurate as possible in the interaction with the elements of the cockpit while ensuring high quality tactile feedback to the user as well as a good perception of the elements of the cockpit, and to minimize task execution errors, disturbances on the driver currently driving and the device latency. User experiments show the effectiveness of our device through visuo-haptic feedback.

Keywords: Virtual reality, haptic device, multi-sensory feedback.

1 INTRODUCTION

Virtual reality systems immerse the user in an interactive 3D virtual environment. The visualization of the virtual scene can be performed for example on multiple screens allowing the immersion of the user (typically for an immersive room, a CAVE™ system) or using a stereoscopic head-mounted display (HMD) which includes the user's field of view [Bowman, 2004]. These systems are used for instance to study and edit a future industrial product during the design process, interactively, i.e., through the use of interfaces, and without needing to build physical prototypes, or to study scientific data resulting from physical simulations [Allard, 2007]. In the industrial sector, especially car industry, they can be of help in the design process and can save significant time and money.
Our research is in the context of the design of a passenger vehicle for which the accessibility and the usability of elements of a cockpit in a driving situation are evaluated by displaying the cockpit in a virtual environment and interacting with the elements (buttons, etc.).
For these ergonomic studies using virtual reality, the accuracy and the ease of interaction must be guaranteed.

2 STATE OF THE ART

In virtual environments, interactions can be performed through devices that can be invasive, like gamepads or the so-called Flystick, and without any tactile feedback. Moreover they can require some technical knowledge to use them. However, in a virtual driving situation, the driver cannot use such devices to interact with the cockpit because they may cause disruption in the driving task, thus inducing cognitive overload. Moreover, the driver needs to be able to interact with the elements of the dashboard without necessarily having to look at them. Also, the driver must be able to rely on his/her sense of touch as he/she does in a real vehicle [Swapp, 2006]. Therefore tactile feedback is important when the user presses a button on the dashboard of the vehicle, as it can return helpful sensory information to the driver and provide additional guidance. This can be performed using haptic devices.
Haptic interfaces include two families, namely kinesthetic force feedback interfaces and touch interfaces. The kinesthetic sense allows feeling the positions and movements of the body, and the forces exerted on it, e.g., the weight of an object, by using proprioceptive sensors located in the

muscles and tendons. The sense of touch allows the feeling of the shape, texture or temperature of objects using different types of sensors located at the skin (e.g., [Pai, 2005]). In recent years, several haptic devices have emerged as commercial products, such as: Sensable's Phantom arm, Immersion's Impulse Engine, or Haption's Virtuose arm.

These systems are generally costly. An alternative to these systems is to consider pseudo-haptics [Insko, 2001, Lecuyer, 2000] consisting in deceiving proprioceptive senses using cheap devices (e.g., vibrators or sponge balls).

Some systems also include input devices that can track the movements of the user to update the virtual scene according to its position and angle, using either mechanical-based, e.g., data gloves (CyberGlove, 5DT glove, etc.) [Bouzit, 2002, Burdea, 1992], or optical-based tracking systems (e.g., [Schlattman, 2007]). Generally, these systems do not include any tactile feedback; nevertheless we can cite the CyberGrasp that includes force sensing.

Although these systems, especially data gloves, allow scale one interaction, they suffer from major drawbacks that are: (i) they require to interact with the hand in a raised position, inducing quick muscular fatigue, (ii) they are very expensive and thus cannot be used by general audience, (iii) they need good technical knowledge to be used, (iv) they are intrusive and require a non-negligible setup time, (v) the workspace of haptic arms are too small to interact in large spaces.

Our main contribution lies in proposing a device with active haptic feedback allowing performing natural movements, without being intrusive, easy to use, thus not inducing cognitive overloads, cheap and it can deceive the user's proprioceptive sensations.

The remainder of this paper is organized as follows: in the next section, we describe the scientific issues and research questions related to our work, then we present the proposed approach that we assess in the following part, before concluding.

3 SCIENTIFIC ISSUES

The aim of our study is to know the criteria for virtual reality allowing a user to:

- Not to induce cognitive overload resulting from the complexity of use and the invasiveness of the device for a driving simulation.
- Be precise during an interaction task with the elements of the cockpit (the driver must be able, for example to press the desired button and not on another one right next to it).
- Ensure high quality of tactile feedback to the user with a good perception of the elements of the cockpit.
- Minimize the task execution errors and disturbances on the driver currently driving, by minimizing the device latency.

At this level, the research questions are:

- What is the added value of tactile feedback to the user?
- How to synchronize visual and haptic sensory modalities allowing interaction without causing additional cognitive overload?
- Has the quality of tactile feedback an effect on the performance of the interaction (time to complete the task and accuracy, subjective evaluation of the user)?

4 PROPOSED APPROACH

In order to achieve our goal, we propose to perform an analysis at several levels: one at the hardware level, another at the software level, and finally at the experimental level.

At the hardware level, we developed an interaction device including tactile feedback, consisting in a ring to which is attached a devoted system with haptic feedback and an optical tracking system to allow tracking the user's finger position interacting with the virtual cockpit (see Figure 1).

First, we limit to interacting with the index used to represent a large majority of interaction tasks done with the cockpit of a vehicle. Haptic feedback will be achieved through two technologies we will compare:

- Using a small vibrator attached under the finger: it is only activated when the user's finger touches the virtual cockpit, so that it can return to the user collision information. The advantage is the low cost of the proposed solution and it can deceive proprioceptive sensations of the user, the drawback is that it does not prevent the penetration of the virtual object (tactile feedback returns only object collision information).

- Using a reduced Spidar [Sato, 2002] type interface consisting in one wire connecting the ring and the back of the driver's seat: the system is based on a thin wire driven by a small DC motor drive attached to the rear of the driver's seat, provides tactile feedback while preventing penetration into a virtual object.

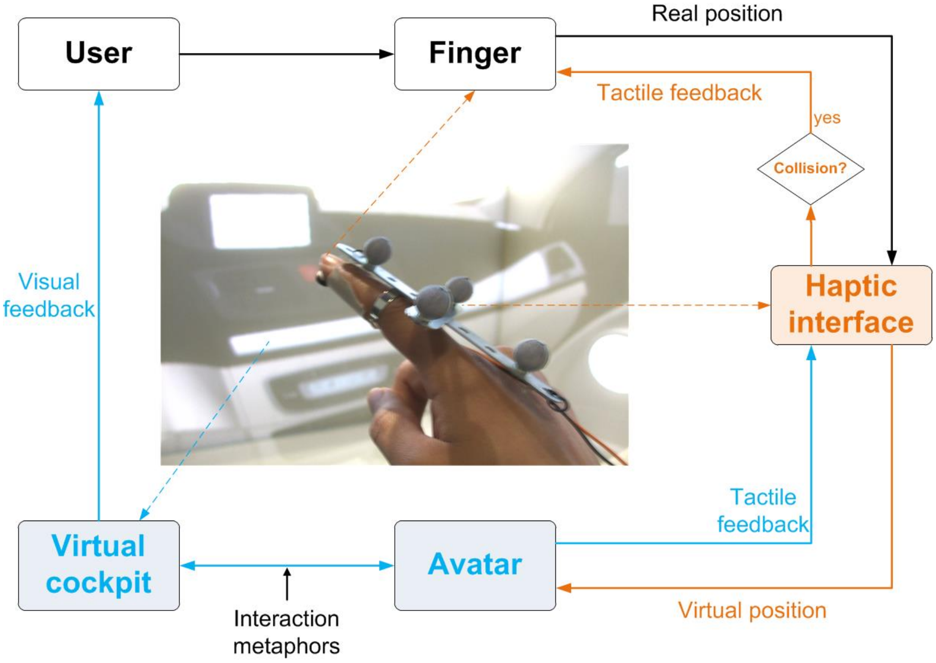

Figure 1. Schematic diagram of the device

Figure 2. Using the device in an immersive environment

At the software level, we implemented the coordination of information returned by the system (optical tracking, collision detection) to return to the user a sense of touch that renders the texture of the virtual cockpit and provides multi-sensory guidance (touch + vision) for good accuracy in the task execution. The scene is rendered and displayed in a 4-side CAVE™ using OpenSceneGraph (see Figure 2).
Finally, at the experimental level, we set up a study to evaluate the performance of the device and the one of an interaction task (completion time of the task).

5 USER ASSESSMENT

2.1 Working hypothesis

Following our scientific issues stated previously, and to assess our proposed approach, we set two assumptions as follows:
H1: The non-feedback system is better than other systems.
H2: The system with multi-sensory feedback (touch + vision) is much more accurate than another without any feedback.

2.2 The experimental setup

In this experiment we tried to evaluate the perception of the user interacting with the system in four different conditions:

1. Without any feedback.
2. With a color change (vision feedback).
3. With haptic feedback (through vibrations).
4. With visuo-haptic feedback (vibrations + color change).

In a first stage, we measured the time to complete the same task in each condition, and asked the subjects to answer a qualitative questionnaire and requested their opinions on the advantages and disadvantages of this system and their suggestions. Several questionnaires as proposed in [Hart, 1988, Witmer, 1998] could be used, however, we choose for simplicity to ask only few questions related to muscular fatigue, immersion quality and comfort (see Table 1). All answers are marked from 0 to 10 (0: none, 10: excellent). The experiment was performed with 12 subjects, both male and female and aged from 22 to 36.

Table 1. User questionnaire

Condition 1 (no feedback)	
Condition 2 (color change)	
Condition 3 (vibrations)	
Condition 4 (vibrations + color change)	
Discomfort	
Ocular fatigue	
Finger fatigue	
Immersion quality	
Vibration quality	
Tracking	
Ease of use	

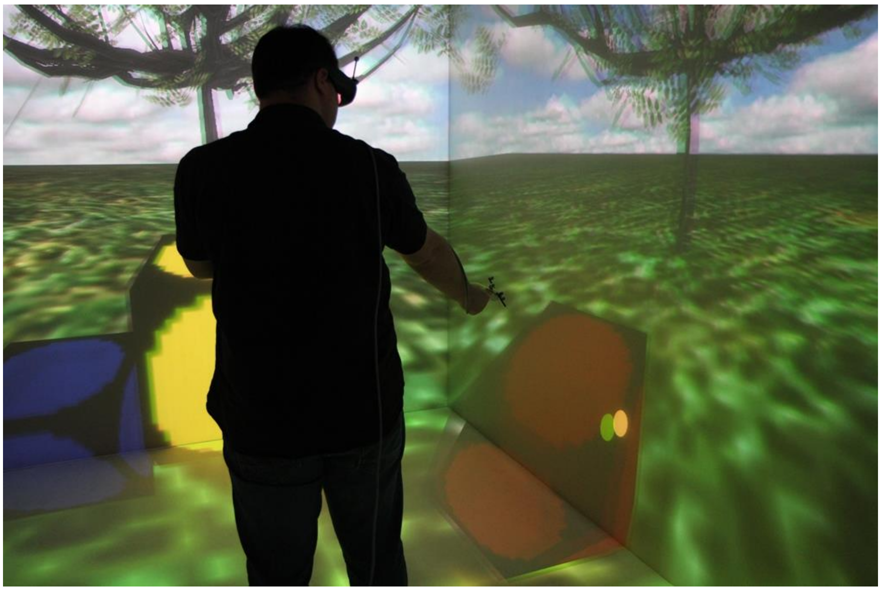

Figure 3. Simple task for user assessment

In this paper we concentrated on simple tasks to assess our device. We asked the subjects to touch four different cubes displayed in a virtual scene at different positions using our device (see Figure 3). The subjects had to touch the cubes in a predefined order to complete the task, following the four conditions mentioned above. In conditions 2 and 4, as visual feedback, when a cube was touched, it changed its color to white. In conditions 3 and 4, as tactile feedback, when a cube was touched, short vibrations were sent to the device.
Note that in this paper we focus on experiments using only small vibrators under the finger and without considering for the moment any cognitive matters.

2.3 Results

We performed a statistical analysis and we got results in accordance with our hypothesis H2 (see Figures 4, 5 and 6).

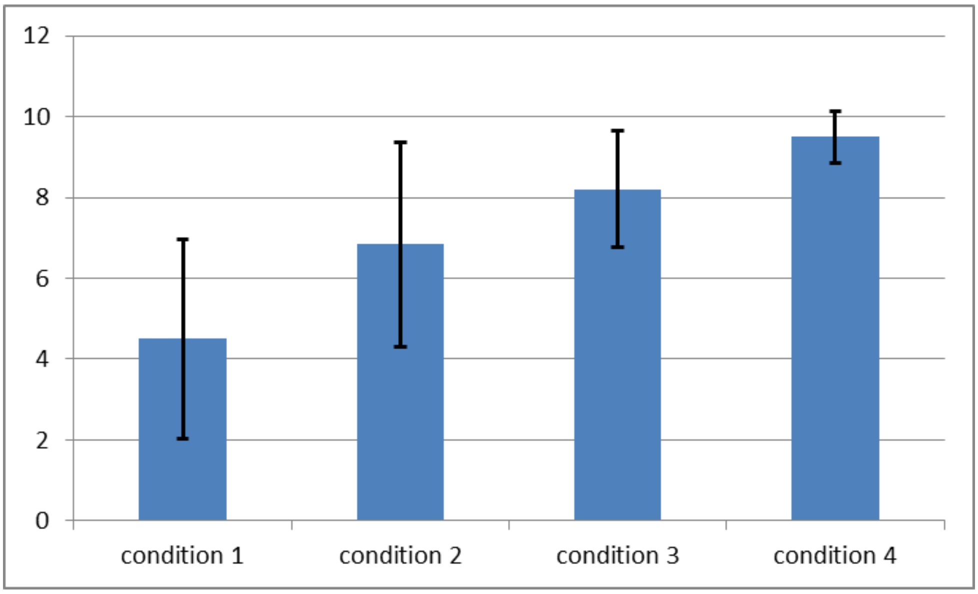

Figure 4. Mean and standard deviation for the general assessment of the device

First, in Figure 4, we remark that for the first two conditions, most of the values range from 2 to 7 for the first and from 4 to 9 for the second condition. Generally, the more values are widely distributed, the higher the standard deviation, thus it is one clue showing that on one hand no feedback is not efficient, on the other hand only visual feedback is not enough to satisfy users.
However, for the last two conditions, namely conditions 3 and 4 which states that the users interact with the virtual environment with haptic and visuo-haptic feedbacks respectively, it is clear that most of the values range from 7 to 10 for condition 3, and 8 to 10 for condition 4, meaning that the values are not widely distributed, in other words, we can say that the perception of the users interacting with the virtual environment is strongly linked with tactile feedback, especially the visuo-haptic one (vibrations + color change).

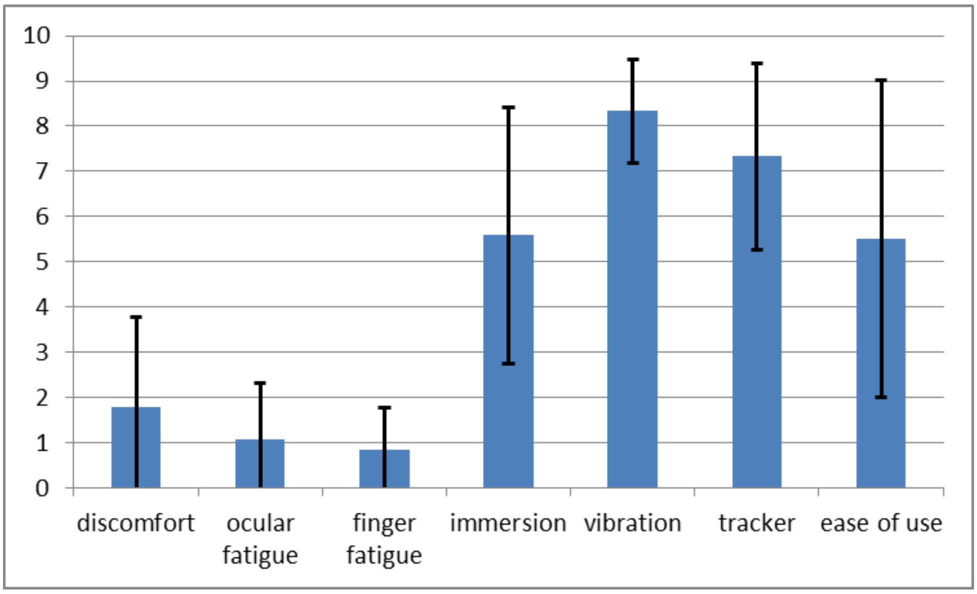

Figure 5. Mean and standard deviation for each criterion of the questionnaire

Figure 5 represents the degree of satisfaction of the subjects for each criterion on a scale from 0 to 10. We note that the system does not cause fatigue, is easy to use and haptic feedback is well appreciated. From Figure 6, without any feedback, the task completion time could not decrease significantly, while with multi-sensory feedback (vibration + color change), the time dramatically decreased for the last two conditions. This shows quantitatively that adding feedback brings better performance, especially, it is necessary to operate a fusion of several senses.

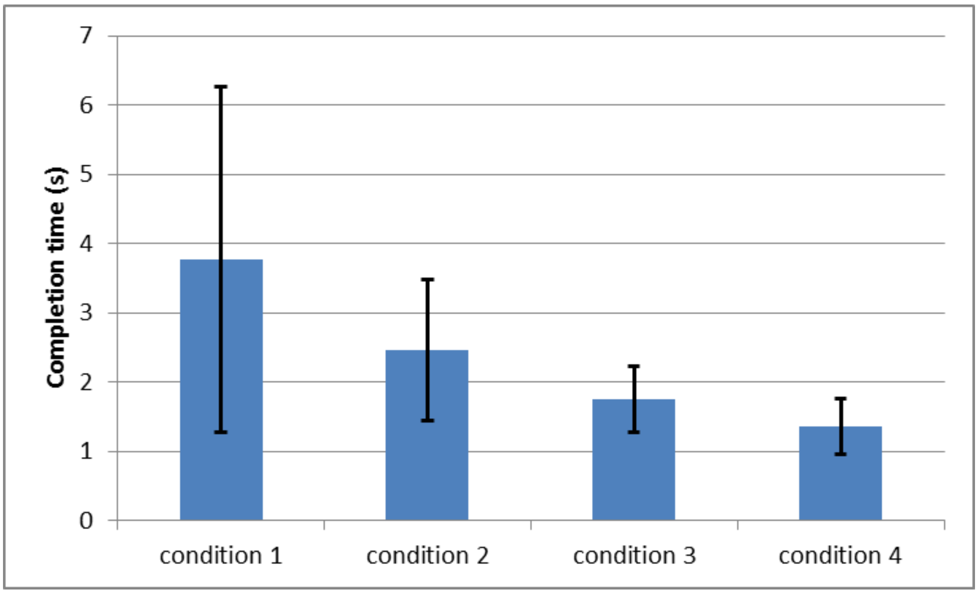

Figure 6. Mean and standard deviation of the task completion time

Finally, we performed a one-way analysis of variance (ANOVA) to evaluate the influence of the conditions on the users. We tested the null hypothesis that there is no difference of user perception depending on the conditions. The obtained p-value ($p=0.000001$) proves what we already assessed above, i.e., there are indeed significant differences between each condition. Therefore, hypothesis H2 is validated.

6 CONCLUSION

We proposed a novel light device devoted for interacting with a virtual car cockpit in driving conditions. This device allows interacting without inducing cognitive overload thanks to its light and intuitive design. We integrated visuo-haptic feedback to maximize the user's performance using low cost technologies, typically vibrators. We assessed our device on simple tasks. Experimental results showed significant improvements when including multi-sensory feedback, thus bringing new insights to design process in industry.

We are currently setting the reduced Spidar type interface to enhance the quality of interaction and so the level of immersion. Experimental comparison with further investigation on the sense of presence and cognitive matters will be conducted in future works. We will integrate our device in a car seat and we will perform our tests in a virtual car.

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