Usability of Glove-based Handling Devices in Virtual Training: Use Case in Automotive Sector

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Abstract

This work analyzes the impact of subjective factors on users' immersive experience, while using glove-based handling devices as input system. A user-study has been conducted on a Virtual Training framework, evaluating usability and mental effort perceived with such devices.

Keywords Gloves --- Handling devices --- Usability --- Frustration --- User study --- Virtual Training

1. Introduction

In the industrial context, the scope of a training session for the operators is to make them autonomous and independent in the execution of the processes, as well as being aware and safe within the work environment [1]. However, considering that the percentage of mistakes made during a training session can be high, it is necessary to employ a training method and tools that allow to repeat the procedure several times with no influence on the real components or interference with ongoing operations, always ensuring the workers' safety. From these premises, considered the great success of technologies such as Virtual Reality (VR) even in the industrial world in the last twenty years, the Virtual Reality-based Training System (VRTS) has been ideated. The VRTS consists in an immersive training system that simulates the workcycle and operations to be learned, with a different level of interaction for the users. Such systems offer several advantages: a greater degree of freedom in the execution of training, as the trainees are independent from the actual availability components and workarea; the repeatability of training to consolidate knowledge and speed up processes; the ability to operate (and also do mistakes) safely only in a simulated world, without incurring costs and risks in terms of personal injury and equipment repair [2].

One of the main problems encountered in non-automated production processes, which are also reflected in considerable difficulty during quality control, is the considerable variability during the process itself. Although this variability is apparently insurmountable as necessarily dependent on the subjectivity introduced by human intervention, it can be at least reduced by increasing and refining the knowledge and skills acquired by the operators during training. To do this, it is important that training methodologies and tools are standardized and effective, aiming to offer the most engaging and realistic experience possible. In the case of simulating manual operations such as assembly/disassembly of components or maintenance interventions, the VR training session can become much more realistic for the operator if, in addition to the typical visual stimuli (and auditory), he/she also receives tactile feedback, with precise and localized vibrations and a return of force on the body [3]. For this reason, aiming to set up a VR input system as user-friendly and comfortable as possible, glove-based handling systems have been introduced. These particular wearable devices are capable of acquiring quantities as bending of the fingers, force exerted by the fingertips, acceleration and rotation of the wrist [4]. Thanks to these sensorized gloves, it is possible to simulate in a more realistic way the user interaction user in the virtual scenario, receiving a vibration in case of penetration with digital objects, as well as a greater awareness of oneself within the virtual scenario, thanks to a more realistic movement of the avatar of their hands.

2. Motivations

Many works in the current literature justify and confirm the use of the handling glove-based devices as an added value in user interaction in VR applications, especially in Virtual Training. Despite this, there is still a lack of user-studies about the use of these devices, neglecting subjective factors that may negatively affect the outcome of the immersive experience itself. For instance, it is fundamental to guarantee a high level of usability and a low level of mental effort required to the user, in order to obtain the expected results of satisfaction and effectiveness of the virtual immersive experience. For this reason, for test purpose, an immersive VR training framework has been created, based on the use of a glove handling device as input system. The selected device, well known in the industrial field, has been tested within two immersive environments and both objective and subjective measurements have shown many insights into the perception of such devices by end-users, whether they have already experienced immersive experiences, or not.

3. Case study

The selected case simulates some phases of the process of Prepreg Hand Lay Up for the rear floor of a car in thermosetting material, with reference to the project "Borgo 4.0".

The Hand Lay Up method of autoclave molding, widely used in the automotive industry, is performed by manually superimposing CFRP pre-completed sheets on a mold [5]. The manual rolling process is carried out by placing on the open mold the uncured material in the form of sheets. The sheets are superimposed according to a certain rolling sequence, interposing between the various layers mechanical elements on the basis of the configuration identified. The thermoset composite sheets and the annealed are arranged on appropriate logistic shelves near the mold in kit configuration together with the operating cards. During deposition, the sheets are consolidated manually using metal or plastic rollers. Then the assembly, in order to polymerize, is inserted into a special bag of plastic material. For the creation of the vacuum inside the bag, a tube from the ceiling is connected to special valves, fixed on the surface of the bag.

Table 1 shows the textual instructions that have been displayed to the users during the immersive training experiences (Fig.2).

Table 1. List of textual instructions given to the user

1	Remove the protective film from the composite sheet #1 on the workbench. Place it in the waste box below.
2	Place the composite sheet (1) on the mold.
3	Take the metal roller from the kit cart and consolidate the foil, eliminating any trace of air trapped between the layers of composite. Place the metal roller on the kit trolley once the procedure is complete
4-6	Repeat actions 1-3 for the composite sheet #2.
7-9	Repeat actions 1-3 for the composite sheet #3.
8	Take the insulating plastic sheet (vacuum bag) from the workbench and cover the mold entirely.
9	Connect the vacuum tube, suspended inside the clean room, to the valve fixed on the surface of the bag.
10	After the automatic suction, to complete the process, disconnect the hose from the valve

4. Experiments

A Virtual Training framework with a glove-based handling device for user interactions has been implemented, using two different software. One is compatible with general drivers of the gloves, with more flexibility but also time required to program the user interactions and feedbacks; while the other is provided with customized drivers for a quicker and easier use of the specific device. Some tests have been conducted on the Virtual Training framework to evaluate usability and mental workload required to the users, with such VR input system. The test phase took place in MARTE laboratory, located within the campus of San Giovanni a Teduccio of the University of Naples Federico II.

Experimental setup Our Virtual Training framework is illustrated in Fig.1. The main software and hardware components are briefly described in this section.

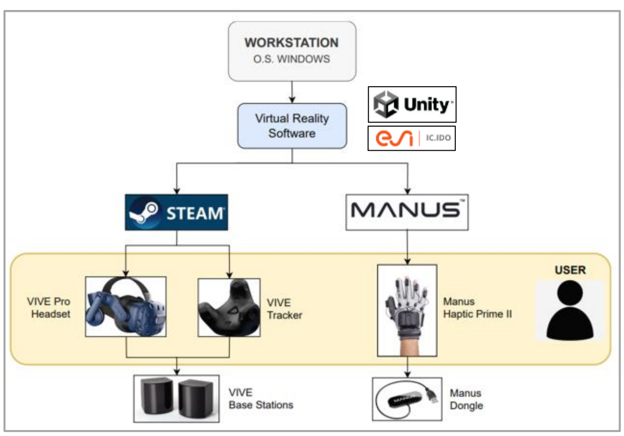

Figure 1. Software and Hardware components of the implemented Virtual Training framework

HTC Vive Pro is one of VIVE's most popular Head Mounted Displays (HMDs) [6]. It has an "outside-in" tracking system, to track the movements of the user's head and hands (and any other tracker), within a playing area, using at least two Base Stations (external infrared cameras) that face each other diagonally.

Vive Tracker: is an unintrusive solution for adding high-precision positional tracking to any associated real-life object (even user's full body) [7]. When used in combination with gloves as MANUS Haptic Prime II, also the hand position information with respect to space can be wirelessly sent to the computer and be reflected in the movement in the VR space. In our case, two trackers have been put on the back of the gloves to track the users' hands.

MANUS Haptic Prime II: is a glove-shaped tracking device that can read the movement of each finger and the direction of the hand of the user. The tactile feedback is achieved through a programmable Linear Resonant Actuator (LRA) tactile module attached to each finger, providing the ability to feed back the tactile sensation of grasping an object in VR space to the glove [8]. This device has been selected because it easily allows to customize the tactile feedback with MANUS Dashboard and drivers. Further, it is compatible with several main VR software (Unity3D, Unreal Engine, Xsens MVN, and IC.IDO) and hardware (HTC VIVE set, Oculus Rift S and Quest 2, Varjo, etc.).

Steam: The Steam (and SteamVR) software platform developed by Valve Corporation [9] has been used for managing and sending the VIVE devices' tracking information to both the VR software.

IC.IDO: It is a commercial VR software, intuitive, versatile and with an industrial approach, produced by ESI Group [10]. The main feature is modularity, which allows the customer to buy and implement licenses only of the required modules, according to the needs. It is one of the VR software already integrated with MANUS, with dedicated drivers and an official version of MANUS Core software specifically customized for IC.IDO [11].

Unity: it is a graphic engine used for the creation of 3D interactive content and video games for several platforms (web browser, desktop, console, mobile device, VR headset, AR device, etc.) [12]. Unity's programming language is C++, but also allows to compile projects in C# and Javascript. It is a representative of the main open-source VR software that also support MANUS drivers, using the basic version MANUS Core software [13].

The implemented systems As anticipated, the same immersive Virtual Training System has been implemented within two software that have offered different functionalities with reference to the input device chosen. The followed training logic, however, is common to both. In particular, it was decided to administer the instructions (Table 1) in textual form, on a 3D panel placed in a fixed position within the virtual scenario (Fig.2).

In addition to these, a second feature guides users during the training: at each step, the loop animation of a "ghost" hand shows the preview of the movement to be performed (Fig.3). Finally, all the sequence of events throughout the training is governed by an *Input-Trigger-Action* logic [14], where the user performs the operations in first person. In particular, when the user grabs the digital object approaching it and closing the fist (*input*), the visibility of a semi-transparent parallelepiped at the object's target position turns on (*trigger*). Once the digital object is transported to the correct target position, the parallelepiped turns green (Fig.4) and the object, once released, is mounted correctly (*action*) and the following instruction appears.

The participants A sample of 16 males, aged between 20 and 30, participated to the experiments (Fig.5). All of them were Industrial Engineering students and had already tried at least a VR headset and controllers for personal entertainment, but no one had experience with a glove-based handling device. In order to have consistent results about the software comparison, 8 people first tried the simulation in IC.IDO and 8 with Unity, then repeating the simulation with the other, after a fixed time (14 days).

Before the test A 6 minutes pre-test phase was carried out for all the users to take the right confidence before the test execution.

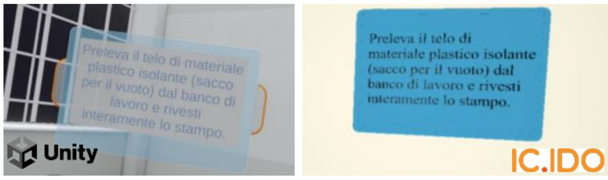

Figure 2. 3D panel with textual instructions in Italian language, within the two immersive environments (Instruction #8 from Table 1)

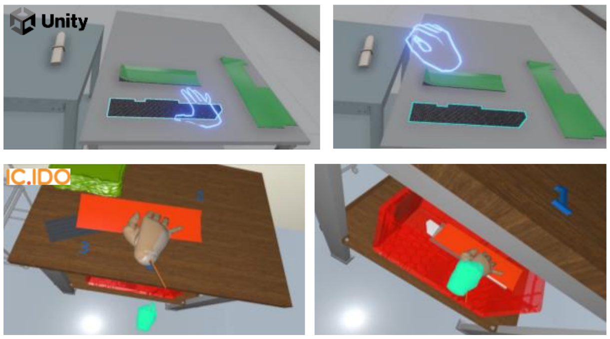

Figure 3. The “ghost” hands show the user the required movement preview within the two immersive environments

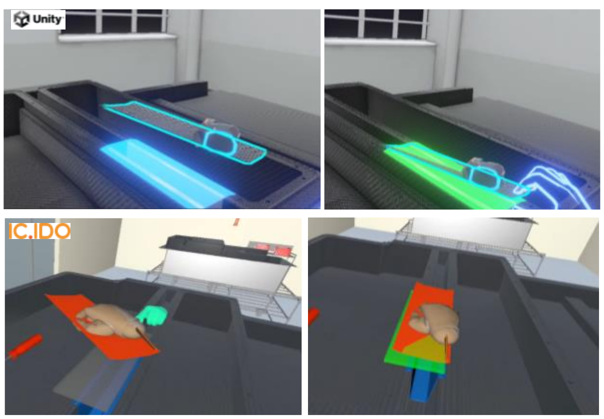

Figure 4. Example of the *Input-Trigger-Action* logic within the two immersive environments for composite sheet #3

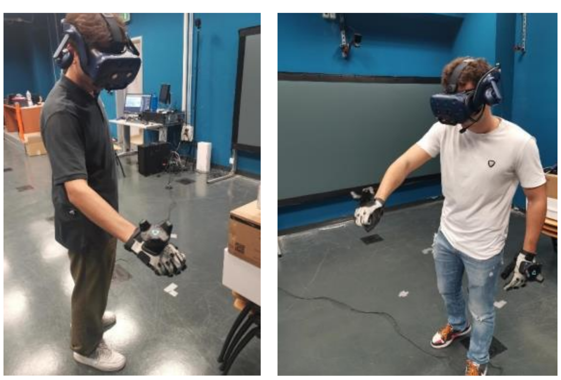

Figure 5. Some participants during the tests

5. Observations

In this section, the results of the conducted tests are described.

Observation #1:Time taken to complete both the VR training sessions has been registered, for each participant. This objective measurement has given first interesting results about the use of the gloves. Fig.6 shows the average time recorded by each participant for both software. For both VRTS, there was a recurring loss of finger tracking, which slowed down the execution of the ongoing task. The difference, however, is that the integrated MANUS diver for IC.IDO has also showed a difficulty in the grabbing actions, as sometimes the user was not able to easily release the digital object, which remained attached to the avatar of the hand. In fact, the time taken to complete the simulation in IC.IDO has resulted to be about 2.5 times higher than in Unity. In this case, the gloves' tracking system and dedicated drivers for IC.IDO impacted negatively on the recorded times, as well as on the concentration of some users, who have defined themselves almost tired and annoyed after a few minutes from the beginning of the VR experience.

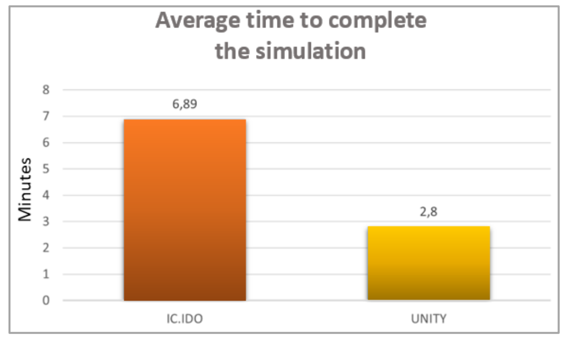

Figure 6. Average time to complete the training sessions

Observation #2: Usability is the capability to be used easily and effectively by a range of users, to fulfil the specified range of tasks, within the specified range of environmental scenarios. The SUS questionnaire [15] has been filled out by the participants after both the VR training sessions, to investigate the user's attitude towards Virtual Training framework with a focus a glove-based handling device as input system. The obtained results are showed in Fig.7: for both the sessions, the judgment is quire the same for the two software (IC.IDO score: 69.22, Unity score: 73.25). Therefore, the overall score of the SUS questionnaire is **72/100**, (which means “falling in grade “B” (which means good”): the glove-based handling system has resulted to be usable and suitable to simulate grabbing and handling of objects.

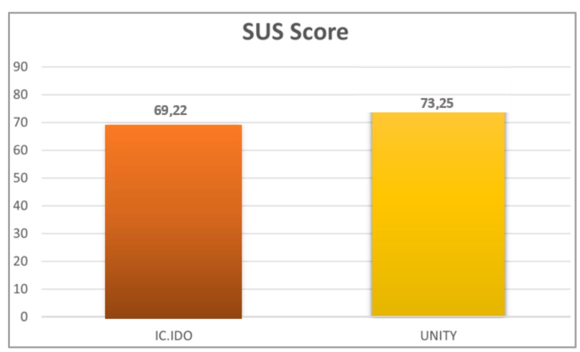

Figure 7. Results of SUS Score

Observation #3: Mental Workload is the volume of cognitive work necessary for an individual to accomplish a task over time. As for SUS, also NASA TLX questionnaire [16] has been submitted to the participants after both the VR sessions. Although on average VR training in IC.IDO had a more negative result (Fig.8) due to the above-mentioned tracking problem, both

VR training sessions were affected by another recurrent issue which prompted some users (6 for Unity and 5 for IC.IDO) to give a fairly severe judgment. Sometimes the glove continued to vibrate for many seconds even after the end of user interaction with a digital object, causing stress and frustration in the user. The average score of the NASA TLX questionnaire is **39/100**, which falls in the "Somewhat high" class. This means that, for the users, the interaction with such devices requires a not negligible mental effort, leading some to prefer their use only if strictly necessary.

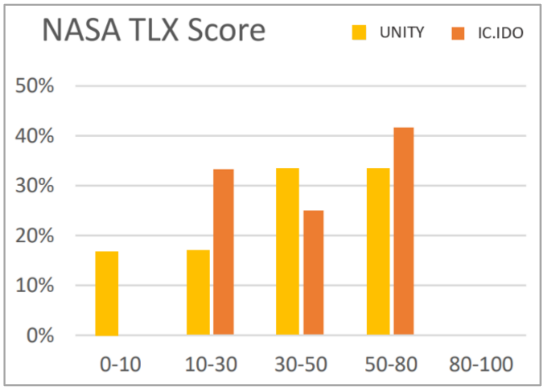

Figure 8. Results of NASA TLX

6. Discussion and Conclusion

This work has analysed the user perception of the glove-based handling devices in immersive Virtual Training applications, in order to obtain the best results from the VR experience. For test purpose, a Virtual Training framework with a glove-based handling device as input system has been implemented within two immersive environments characterized by a different level of integration with the device's drivers. The Virtual Training systems have been tested and judged by a group of 16 participants, in terms of usability and mental workload required to use this type of handling device as input system in the VR sessions. The input system has resulted to offer a quite satisfying usability level, but requires a not neglectable mental effort to the users, showing some issues. In fact, some users sometimes complained of fatigue in the hands after a few minutes of use of the glove, while other experienced frustration due to tracking and vibration issues, feeling that these were slowing down the execution of ongoing operation. These issues have demonstrated that also the level of integration of such devices with the selected VR software is a crucial decision, that may reflect also on the user's perception during the immersive experience and his/her results after the training session.

7. Impact of the Research

This work aims to give a significant contribute to the literature about the use of glove-based handling devices in VR applications, especially in Virtual Training. In particular, the work highlights the importance and impact of subjective factors such as usability and mental effort perceived by the user, while using such devices, on the effectiveness of the whole immersive experience.

8. Acknowledgements

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