An Integrated Haptic System combining VR, a Markerless Motion Capture System & Tactile Actuators

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Abstract

In the industrial environments, it is common that robotic or remote interaction with both rigid objects and soft or deformable objects is required. However, it is usual in such an environment that only one mode of manipulation is used, and that little or no distinction is made between rigid or deformable objects.

The ability to "feel" or touch an object easy a naturalistic way to determine what type of object is being manipulated. By feeling an object appropriate manipulation techniques can be applied.

A novel Virtual Reality (VR) interface is presented that incorporates tactile feedback in order to "feel" objects being manipulated.

Incorporation of an important extra "sense" into such a system allows far more nuanced and dexterous interaction to occur in manufacturing environments that may be "messy", have imprecisely located objects or that have a range of different materials present.

1. Introduction

One of the first things we learn as infants is how to interact and manipulate objects in our environment. Being able to visually focus on an object is an important sense used in this act. However, the ability to touch or feel is also vitally important [1].

Robots and remote manipulation equipment often perform activities like picking, assembling or tightening in an industrial environment, but are capable of far less sophisticated manipulation than even a baby of only a few weeks old. Up to very recently only a single sense, vision, has been used in this task. The skill to feel the objects, to touch them and by doing so perceive their shape, roughness, stiffness, weight and dimension, is an important capability that has been underutilised. This is may be because until very recently the technologies did not exist to emulate kinaesthetic feedback [2-4].

New devices and integrated system are coming to market that providing tactile and force feedback [5-7].

However, these systems are often built for very specific purposes and are difficult to repurpose in order to produce a holistic sensation of object manipulation. Usually cutaneous vibro-tactile feedback is used. VR technologies are currently proposing higher quality of visual feedback, enhancing more immersive experiences in different applications' scenarios [8-11] but little development has been performed on haptic feedback devices other that than providing uniform vibration when virtual objects are touched.

We propose an integrated architecture, which aims at increasing the immersion of the user while interacting with virtual objects in a VR scenario. The system is composed of a VR interface and a motion capture system plus a VR engine, which emulates the dynamics occurring between the end-user (i.e. the worker) and the objects. Experiments have been performed in order to validate the ability of the system to discriminate between different softness (and hardness) of objects.

The paper is organised as it follows: Section I presents an overview of the system, Section II details a set of

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experimental conditions and finally, Section III and IV report the results and discussion.

2. Materials & Methods

The Virtual Reality and Haptic System is made of 3 main functional elements, namely, (i) an Oculus Rift Head mounted display (HMD), a (ii) Leap Motion Controller, and (iii) a wearable haptic system or device (Figure 1).
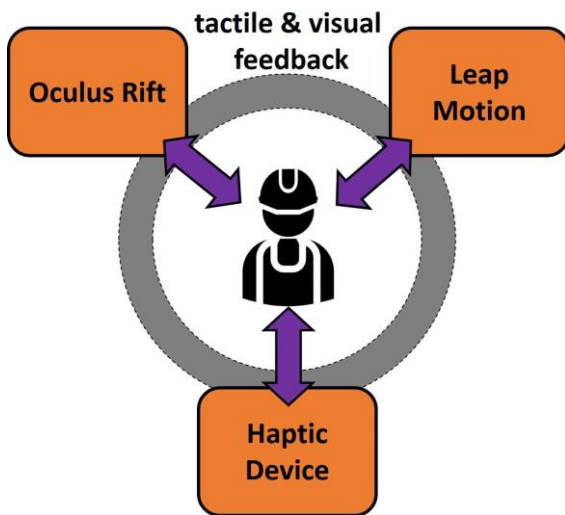
Figure 1. Overview of the worker-centred functional set-up.

2.1. Experimental set-up

An experimental setup was designed and integrated, which perform tactile feedback through a VR environment implemented in Unity 3D development platform (Unity 5.3 Game Engine). End-user hand movement are captured throughout the Leap Motion controller, processed under the VR environment and then applied to the same hand via a wearable set of 5 vibro-tactile actuators which are positioned on the user fingertips.

The Haptic device was created in our laboratory and is made of 5 Precision Micro-Drives actuators, combined with a DRV2605 Adafruit driver and a wireless Bluetooth RF Transceiver HC-06.

The actuators are controlled via the Bluetooth transceiver which communicates with a Personal Computer which simulates the VR environment (including the physical characteristics of the virtual object) (Figure 2).

All the five vibro-tactile actuators are driven by DRV2650 haptic motor driver connected to the same I2C bus of the microcontroller via a TCA9548A 1-to 8 multiplexer [12-14].

The Leap Motion controller performs motion recognition of the users hand through visual processing and it communicates the hand configuration and position in the VR engine.

The physics engine in the VR environment computes the virtual force for the haptic device. Finally the haptic system stimulates the user hand via modulated vibro-tactile feedback. An overview of the main functional role of these system components is reported in Figure 3.
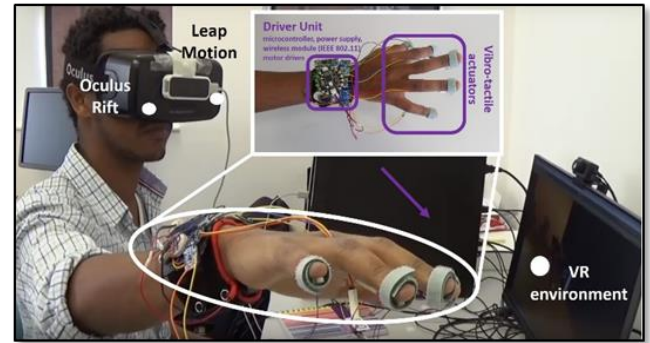

Figure 2. The experimental hardware set-up.

2.2. Experimental protocol

An experiment has been performed in order to evaluate the discrimination of different stiffness under the VR environment interaction throughout the vibro-tactile feedback. In the experiment, a single actuator on the index fingertip has been used.

Five virtual springs were designed on the VR environment and subjects were asked to distinguish between springs that have different stiffness by visually observing compression (visual feedback only), by feeling the compression (tactile feedback only), and by a combination of both (visual and tactile feedback).
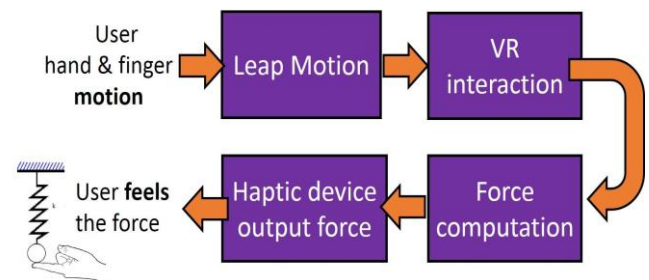
Figure 3. Overview of sensorial functional system.

To implement the interaction between the user hand and the virtual springs, the Unity physical engine has been used, allowing the detection of the effective collision

between the fingertip of the subject and the extremity of the spring.

Dynamically, the springs were modelled by adopting a linear model, namely the law of Hooke ($F = -K \cdot x$, where F is the elastic force of the spring, K is the stiffness and x the applied displaced compression – Figure 3).

Springs were randomly shown on the screen, according to different stiffness values. The subject was asked to touch the springs and determine which one of the two spring was stiffer. Finally, the subject had to push a VR selection button in order to register his/her answer within the system (Figure 4).

Ten subjects were recruited (5 males and 5 females, age: 21-33). The experimental protocol was organised as it follows:

- acquaintance phase (5 min)
- visual feedback only: presentation of standard spring vs spring with random stiffness equally distributed (50 trials)
- pause (5 min)
- tactile feedback only: presentation of standard spring vs spring with random stiffness equally distributed (50 trials)
- pause (5 min)
- visual and tactile feedback: presentation of standard spring vs spring with random stiffness equally distributed (50 trials)
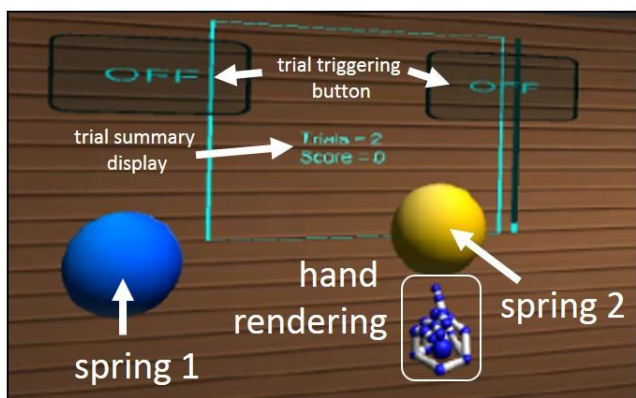

Figure 4. The VR user interface, developed in Unity 5.3 Game Engine.

All the data of the 10 subjects was collected, saved and processed. This is shown in Section 3. A questionnaire was also submitted to each subject at the end of the experiment in order to evaluate the perceived difficulty of the experiment and the realism of the VR environment compared to an equivalent experiment where the subject interacted with a real set of mechanical springs.

3. Results

Psychophysics studies were set in order to study the performance of the haptic devices for the discrimination of the different magnitude of stiffness of the virtual springs.

According to this approach, the *Two Alternative Forced Choice* (2AFC) method was used. This method works by varying the level of stiffness to get the minimum amount of stiffness difference - namely the *Just Noticeable Difference* (JND) - which can be detected and perceived by the user. The method was applied to the data acquisition performed under the *Visual Feedback* only, the *Tactile Feedback* only and the combination of both feedback modalities.
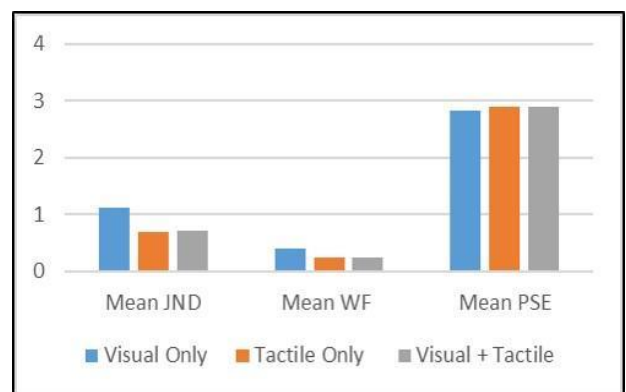
Figure 5. Just Noticeable Difference (JND), Weber Fraction and Point of Subjective Equality (PSE) mean values of the experiment with Visual Feedback, Tactile Feedback and both ones (blue, orange and grey bars, respectively).

The proportion of the correct responses of each subjects were finally plotted against the stiffness values and compared to the effective standard stiffness value. These points were then fitted with a sigmoid curve fitting function. From these psychometric curves of each feedback modalities, *Weber Fraction* (WF) and *Point of Subjective Equality* (PSE) - which are the stiffness value corresponding to 50% of correct response, 25% and 75% of correct responses, respectively - were used to determine the JNDs.

By averaging across all the subjects, a final JND value of 1.12 (22%) was found when experiencing the stiffness under the Visual Feedback only, whereas a 0.71 (14%) value was obtained with the combination of the Visual and Tactile feedback (Figure 5).

Results about the realism of the Virtual Reality environment and subject perception of his/her immersion and experience were also inferred from the answer to the survey completed at the end of the experiment. The survey was collected to study the encountered difficulty during the discrimination task as well. The average

difficulty of the task was rated at 1.6 in a range between 1 (i.e. no difficulty) to 5 (high difficulty). Similarly, the realism of the haptic perception was rated at 3.6, where a value of 1 was set as 'not realistic' and 5 was set as 'highly realistic'.

4. Discussion

The results demonstrate that tactile feedback provided through vibro-tactile actuators can support stiffness perception in a VR environment. These values are also within the range of JND values from other haptic feedback devices in the literature and, therefore, low cost and portable device can be used for virtual haptics applications. These results were also consolidated from the answers of the survey.

This study shows that providing the ability to "feel" provides an invaluable extra communication channel that used in conjunction with visual perception significantly improves immersion. This has two ramifications, firstly remote operation of manipulative devices used in industry, such as used robotic surgery, or those used in hostile or hazardous environments, could greatly benefit from modulated haptic feedback, secondly this extra sense may provide valuable extra data about the environment to autonomous systems.

As the study shows combining both visual and haptic information has capability to greatly increase perception about objects in a simulated environment. Combining this with a learning system that correlates these two senses could provide a powerful way for a system to better perceive its environment.

The study has shown how relatively inexpensive, "off the shelf", equipment can be used. It is envisaged that further development could use alternative technologies; for example an integrated system created that could be combined with smart devices and Mixed Reality in a pre-production manufacturing chain.

If creation of autonomous system is required then a co-operative approach, whereupon the AI learns from human interaction, may be fruitful. Adding the extra dimension of touch and incorporating this with a vision system may not only be of benefit to human remote interaction but also provide a powerful conduit towards more aware learning systems.

5. Video Demonstration

The following link provides a quick video demonstration of the experimental set-up: video link.

Acknowledgements

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