Evaluating Two Novel Tactile Feedback Devices

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Abstract

Adding haptic feedback to virtual reality simulations and telepresence applications increases immersion to human users. As for some applications the use of force-feedback devices is impracticable or not sufficient, tactile devices can be utilized as alternative or as supplement. This work investigates two new tactile devices, which use different technologies for generating tactile feedback. These devices are evaluated by experts for two applications, for a virtual reality simulation, and for teleoperating a hand-arm system.

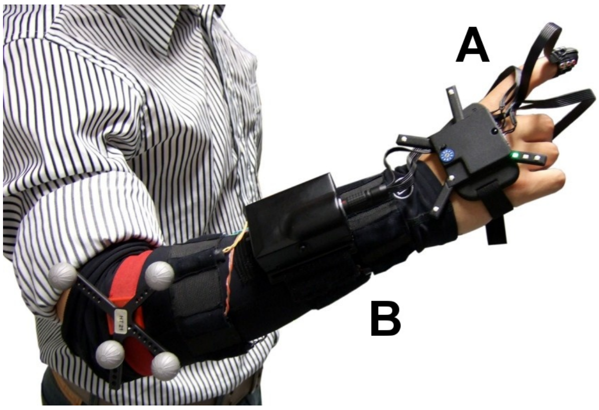

Figure 1: Two tactile devices on a human hand and arm: (A) The finger tracking device with tactile feedback at the finger tips, which is a collaborative work of A.R.T. and Volkswagen, and (B) the DLR vibro-tactile feedback device.

1 Introduction

Haptic feedback can be split into kinesthetic and tactile feedback. A tactile display is a human-system interface, that generates tactile stimuli for human skin. There are tactile interfaces for several applications, like teleoperation, laboratory analysis, sensory substitution, surface generation, braille systems, and games, see [1].

Recently, two new tactile devices were introduced, i.e. (A) the A.R.T. tactile finger feedback device [6] and (B) the DLR vibro-tactile feedback device for the human arm [5], illustrated in Fig. 1. The former displays tactile information to finger tips, the latter generates vibrational feedback to the forearm. Both were designed to increase immersion in virtual simulations.

This paper gives a short technical description of these two devices. It introduces two possible applications in which these devices can be used, namely haptic VR-simulations and teleoperating a robotic hand-arm system. These systems have been evaluated by a group of experts.

2 System Description

The two tactile devices that are investigated in this publication are based on different techniques for generating tactile feedback. This section gives a technical description of the devices' functionality (for a short overview see table 1).

2.1 A.R.T. Tactile Finger Feedback Device

The A.R.T. tactile finger feedback device (FFD) shown in Fig. 2 is extending the A.R.T. finger tracking device with tactile feedback at the finger tips [6]. It is tracked by an A.R.T. optical tracking system. To this end, the device is equipped with active infrared markers (LEDs) for three fingers and the back of the hand. The LEDs for the fingers are mounted on thimbles, which are opened on the lower side. The maximum update rate for tracking the hand target is $60\,Hz$. As the three finger LEDs are activated time-sequentially, the update rate for each is $20\,Hz$.

To provide tactile feedback, three shape memory alloy wires are wrapped around each thimble, Fig. 3. These wires have a diameter of $80\,\mu m$, and a length of $50\,mm$. The state of each wire can vary between

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Figure 2: The A.R.T. tactile finger feedback device (FFD).

a contracted and a relaxed configuration, depending on its temperature. They are activated using a pulse width modulation (PWM) signal. The contracted state is achieved for high temperature $T > 65°C$ using a high duty-cycle. With lower frequency PWM signals also vibrations can be induced to the wires. Therefore, two different kinds of tactile stimuli are possible: short and intense contractions, and vibrations. The communication to the device is wireless using a zigbee radio transmitter.

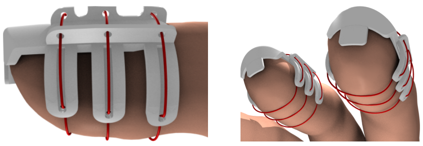

Figure 3: Schematic view of FFD thimbles.

2.2 DLR Vibro-Tactile Feedback Device

The second tactile device investigated is the DLR vibro-tactile feedback device (VTD) [5]. The purpose of this device is to generate vibro-tactile stimuli on a human forearm. It is equipped with 12 groups of vibration motors, each containing two cylindrical motors that are rotating in opposite direction. The motor groups are arranged in two rings around the forearm, see Fig. 4. In a previous evaluation [5] this arrangement has turned out to be a good compromise between resolution and perceivability of stimuli. Each motor group can be controlled separately. The vibration speed of the motors increases with applied voltage and reaches its safe maximum at a voltage of $7\,V$ a frequency of more than $250\,Hz$. The time constant of the motors employed is around $50\,ms$.

Table 1: Features of the tactile feedback devices

FFD	VTD
Tactile feedback at finger tips	Tactile feedback to human arm
Shape memory alloys generate tactile feedback	24 vibration motors in 12 groups generate tactile feedback
Wireless data communication	USB Connection
Short delay in tactile feedback ($50\,ms$)	Motor time constant of about $50\,ms$
Built-in active markers for optical tracking	Built with standard components
Adaptable for individual finger sizes	Variable intensity possible

The device is provided with USB connector for fast and easy connection to a computer. Communication and motor control is an order of magnitude faster than the motor dynamics.

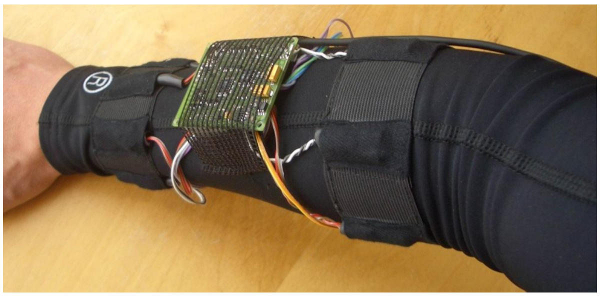

Figure 4: The DLR vibro-tactile feedback device (VTD).

3 Applications

Typical scenarios for human-system interfaces are virtual reality (VR) simulations and telerobotics. For both scenarios an application is presented in this section using one or both of the investigated new tactile devices. Both devices are used to navigate in virtual worlds and feed back collision information. In a second application the FFD is used to command a robotic hand-arm system and feed back information on encountered forces.

3.1 Tactile Devices for Haptic VR-Simulations

A first application, for which the two tactile devices are examined, is tactile feedback from VR. The used tactile

Figure 5: A human operator is evaluating the two tactile devices by exploring a virtual model of the German Micro-Satellite BIRD. The pose of the human arm and fingers are tracked optically by A.R.T. infrared cameras and visualized in the virtual world (yellow cylinder and hand at the top right corner).

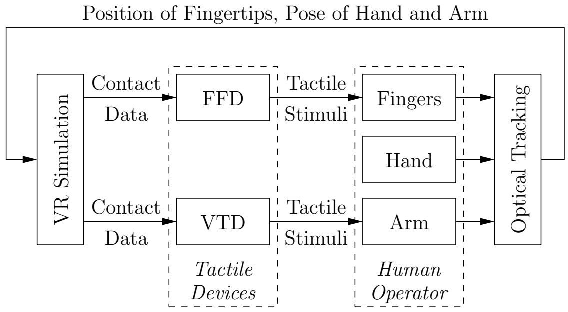

Figure 6: Functional diagram of the tactile VR-setup: Collisions between the virtual representation of the human arm and the virtual scene is sent to the two tactile devices. They activate their actuators to generate tactile stimuli for the human operator. The reaction of the operator is measured by an optical tracking system and the pose of virtual representation of the human arm is updated.

devices enable a human operator to explore a virtual scenario while perceiving collisions. This kind of simulation is used for several purposes, psychological studies, training of mechanics, assembly verification, and gaming.

The employed virtual scenario consists of a virtual model of the German satellite BIRD, Fig. 5. The human hand is tracked optically using A.R.T. optical tracking and the active markers of the FFD. As the VTD has no tracking equipment included, an optical marker is put on the elbow of the human arm. Thus, the human is able to move his forearm, hand and fingers inside the virtual world.

While moving, both tactile devices display concurrently collision information from a virtual environment to the human operator, Fig. 6. Thus, the human operator is able to perceive contacts with the finger tips as well as collisions of the virtual arm; he/she can explore the virtual scene. As the VTD consists of several vibration motor groups, the operator is also perceiving the location of collisions on his arm.

3.2 Finger Feedback for Teleoperated Robotic Hand-Arm System

In a second application the FFD is used in combination with a robotic hand-arm system, in order to telemanipulate this robotic system, Fig. 7. Telerobotic systems are necessary for operating in distant, unreachable, or hazardous environments, for example telerobotic systems in space for on-orbit servicing, minimal invasive surgery, or maintenance of nuclear plants.

The employed hand-arm system is composed of a DLR robot hand II [2] mounted on a DLR light weight robot III (LWR) [3]. The robotic system is coupled to a human operator through positioning the robotic hand and arm according to the measurements of the tracked human hand, Fig. 8. Hence, the pose of the human hand base is used to command the LWR, and movements of the human fingers are scaled and added to an initial pose of the robotic fingers. Position scaling is necessary due to the different sizes of the human and robotic hand. The unmapped fourth finger of the robotic hand is kept in a secure position. All position signals from the FFD are filtered to take care of noise and different sampling times (the robotic system is running at $1\,kHz$).

Tactile feedback information is generated from the error between commanded and measured positions of the robotic hand's fingertips. Therefore, the operator is able to perceive contacts of the robotic hand.

4 Experimental Results

For both applications an experimental setup was built and tested by eight experts from the field of robotics and/or teleoperation. These experts were interviewed afterwards to obtain their qualified opinion.

For the VR application the human operators were able to explore a virtual satellite with their hands and arms, while perceiving contacts through the two tactile devices. In the experiments the VR simulation including tactile feedback was compared to pure VR visualization. All subjects stated, that immersion was increased for the simulation where tactile feedback was present. Especially the concurrent use of both devices improved this

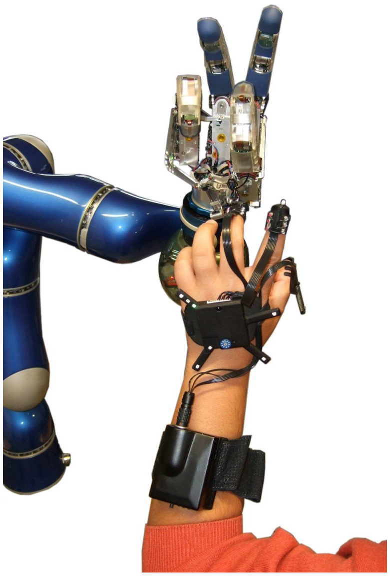

Figure 7: The DLR Robotic Systems mimics the movement of the human operator. The operator perceives contacts of the robotic hand.

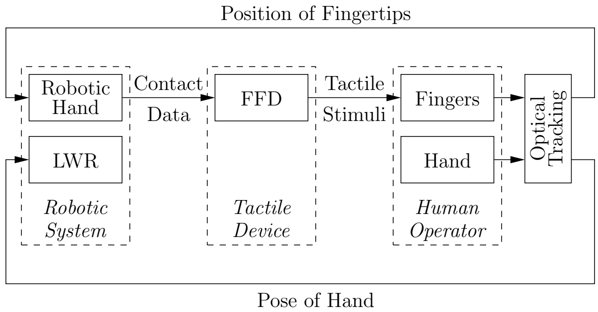

Figure 8: Functional diagram of the tactile teleoperation setup: Collision forces of the robotic fingers are sent to the tactile device. It activates its actuators to generate tactile stimuli for the human operator. The reaction of the operator is measured by an optical tracking system, to update the configuration of the robotic system.

impression for the implemented VR application. Furthermore, all subjects agreed, that for both devices contact impulses are perceived more prominently than persisting contacts or sliding on surfaces.

In the second application, the robotic hand-arm system could be moved in free space and the hand was used to grasp several objects, stiff and soft ones. The contacts were displayed by the FFD, but the actual contact force could only be estimated by visual inspection of the hand or the object. Grasping, placing, and manipulating an object was possible using this human-system interface. In order to do sophisticated manipulations, which the hand is capable of, a more diverse feedback is necessary.

5 Conclusions

Two different tactile devices have been evaluated for two applications, a virtual reality simulation, and teleoperating a robotic hand-arm system. Each device has several advantages. The DLR vibro-tactile device is capable of displaying tactile feedback on 12 different locations to a human arm and can be commanded with a high sampling rate. The A.R.T. tactile finger feedback device is wireless and has already integrated active markers which allow for accurate optical tracking.

Both devices have demonstrated to increase immersion in VR. The FFD can be used as a telerobotic human-system interface. As both devices give tactile feedback to different parts of human skin, it is sensible to use them concurrently for tactile applications.

For future work it should be evaluated if the two tactile device are also suited for manipulation tasks inside VR scenarios, e.g. virtual assembly verification [4]. Furthermore, it seems promising to compare different strategies of actuator control, for instance emulating continuing contacts by pulsing stimuli or using intermediate levels of exertion for the shape memory alloys instead of only turning on and off.

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