Tactile Feedback at the Finger Tips for Improved Direct Interaction in Immersive Environments

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ABSTRACT

We present a new tactile feedback system for finger-based interactions in immersive virtual reality applications that consists of shape memory alloy wires wrapped around tracked finger thimbles. The wires touch the inside of the finger tips and provide an impression when they are shortened. We use this system to communicate finger contacts with virtual objects in an application for usability and reachability studies of car interiors. Our experiments and an initial pilot study revealed that this type of feedback helps users to perform direct manipulation tasks with more reliability.

Keywords: Direct Interaction, Tactile Feedback, Shape Memory Alloys

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism - Virtual Reality B.4.2 [Input/Output and Data Communication]: Input/Output Devices – Channels and Controllers

1 INTRODUCTION

The automotive industry performs numerous analyses during the development process of new car models. Some of them have the potential to be performed within virtual environments. In contrast to common hardware mock-ups, virtual models are available in very early phases of the development process. They can be easily modified, manipulated and investigated by tools unavailable in reality, such as arbitrary cutting and shaping tools.

The use of virtual environments for ergonomic studies in a car interior is particularly challenging since the realistic interaction with various parts of the interior needs to be supported. Two things are essential for this type of application in a CAVE-like environment: the real hand has to be exactly registered to the virtual hand to allow reachability studies and the users have to be able to recognize collisions of their fingers with virtual objects for reliable grasps and manipulations. By observing users during direct manipulation tasks in our CAVE-like system we found that it is difficult to judge the fingers' exact position and pose in relation to virtual objects on a purely visual basis. One problem is that the manipulation of small parts often requires grasps which occlude the manipulated object. In addition users have to focus the display to see stereoscopic images. If the focus shifts to the hands, images of virtual objects located near to the hands are difficult to fuse. Head-mounted displays are an alternative to avoid some of these problems, but according to our experience the acceptance by engineers and designers is very limited. Displaying a virtual hand with a positional offset to the real hand cannot be used for reachability studies.

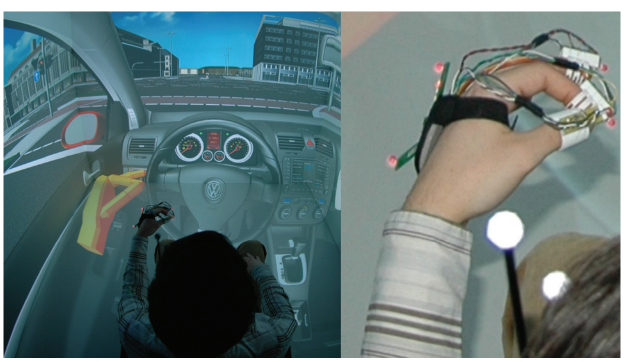

Figure 1: User interacting with a virtual car interior in the CAVE (left), finger tracking system with our tactile feedback device at the user's hand (right)

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We developed a system for the finger tips to provide appropriate tactile feedback during direct interaction in immersive environments. The system consists of tracked thimbles for the fingers with thin shape memory alloy wires wound around each thimble (fig.1). The wires can be shortened by slightly heating them up by an electrical current. This effect is used to create an impression on the inner side of the finger tips, where the wires touch the skin of the finger. We use the tactile feedback to report individual finger collisions to the user during an interaction with virtual objects. An initial pilot study shows that the collision information presented by our tactile feedback system (fig.1) improves the reliability of direct interaction techniques for our usability scenarios.

2 SHAPE MEMORY ALLOYS

Shape Memory Alloys (SMA) are characterized by the ability to alter the shape due to temperature changes. These materials have two distinguishable crystalline structures – Martensite, the low temperature state and Austenite, the high temperature state. By heating the material it can be forced to turn to Austenite, while when cooling down, it will return to Martensite. The conversion is characterized by a hysteresis, making it impossible to derive the material state from temperature, impeding a simple control loop.

Objects can be forced to have a certain shape in each state by training them. Shapes can simply be different lengths of a wire for the two states. There is a trade-off between elongation length and durability of the material. For a 2-way effect aiming at durability only around 2% of length change should be trained [NJ03].

Besides applications in commercial products, e.g. as temperature sensors, there are few other approaches for providing tactile feedback based on shape memory alloys. Arrays of pins used as tactile displays are presented in [WPFH98, VPHS05]. These devices can be attached to input devices to provide additional information. [NJ03] mounted an actuator in a vest which stimulated the user's skin by pins driven by SMA wires.

3 DESIGN OF THE TACTILE FEEDBACK ACTUATORS

From observing users during ergonomics studies for car interiors we had the impression that unobtrusive contact feedback at the fingertips would make the typical interactions with virtual car objects much more reliable. We decided to build tactile feedback

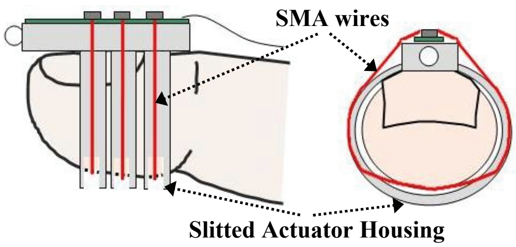

Figure 2: Schematic view of a thimble device

into thimbles for the fingertips. The idea was to use thin SMA wires wrapped around a thimble, which is open on the inner side of the fingertips allowing the wires to be directly in contact with the skin. The wire contraction creates a localized sensation on the fingertip, which should be easy to perceive (fig.2).

The thimbles were created in a selective laser sintering process using polyamide. We developed four prototypes with incrementally improved designs. The process started with a single thimble housing one SMA wire for proof of concept leading to the final prototype, combined with an optical finger tracking prototype developed by A.R.T. GmbH (fig.3). A critical parameter is the fit of the thimbles on the users' finger tips. ISO 33402 describing hand parameters does not specify the outer phalanges' lengths and circumferences. So we chose the dimensions of the thimbles by simply averaging the hand parameters of eleven persons. However people with either rather big or quite small fingers would require the development of adjustable thimbles or thimbles of different sizes would have to be provided.

Another challenge is the connection of the SMA wires to the power supply, which is commonly done by a proprietary soldering process. Improper soldering can result in losing the memory effect. Instead we chose to clamp the wires with screws on the back of the thimble. As mentioned before only small length changes can be realized if a long lifetime of the actuators is important. One of our first tests aimed at the recognizability of these small wire contractions. We found that a 50mm long wire wrapped around the first thimble prototype shortens about 1.5-2.5mm by applying a current. Although this creates only a very small impression on the skin users were able to notice the effect without problems.

The incremental design process led to a prototype consisting of a small backbone for holding the screws and thin rims around the finger. There are three actuators for the middle and index finger and two actuators for the thumb. This final design showed a good compromise between stability and wearing comfort.

We conducted experiments with a set of different alloy types and diameters to select the appropriate wires and identify the control parameters for the electrical design. To achieve a rapid transformation the actuators have to be as thin as possible, of course limited by the tensile strength of the material. Tests showed that 80µm wires have enough tensile strength for our purposes and showed the best dynamic performance. The shape memory alloy is directly heated by electrical current using a pulse width modulation (PWM) signal to initiate the shortening process. We utilized the skin as a heat sink for the wires since there is no risk for the users to contract burns if the actuators are thin enough and the transformation temperature is reached within a short time – for the 80µm wire in less than 50ms.

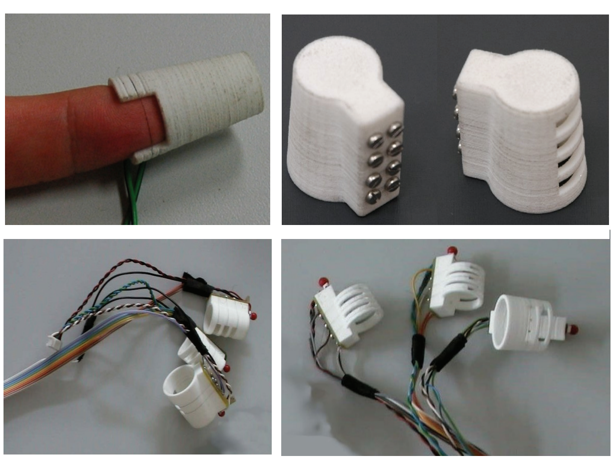

Figure 3: Four iterations of the feedback system.

4 SUMMARY

Our new tactile feedback system consists of an optically tracked thimble for the index and middle finger as well as the thumb (fig.4). Shape memory alloy wires are looped around each thimble. The shortening and relaxing of the wires is controlled by a microcontroller, which receives commands from the virtual reality application. We use the tactile feedback for communicating finger contacts with virtual objects to the user in a projection-based environment. Our pilot study revealed that users clearly preferred the tactile feedback over a system without feedback and felt much more in control of manipulation tasks in the car interior. Users pointed out that the way the feedback was provided – by an impression at the finger tips – matches well the grasping actions of the application. This sensation is quite similar to what is felt when touching objects.

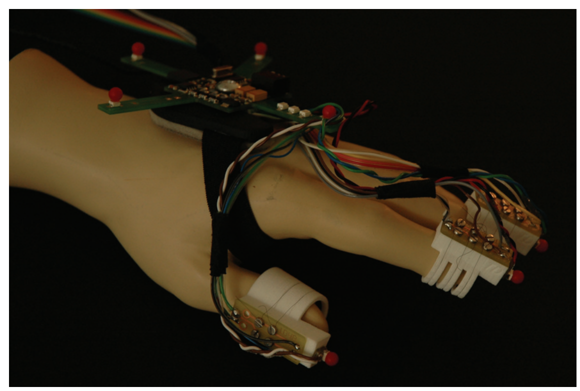

Figure 4: Final prototype of our tactile feedback system combined with the finger tracking system by A.R.T.

Adjustable thimbles for different hand sizes, a wireless solution, and improved response times are further steps in the development of our tactile feedback system. The development needs to be accompanied, guided and verified by extensive user studies. Based on the experience with our current implementation, we are convinced that the combination of precise finger tracking with our tactile feedback approach has the potential to significantly facilitate direct finger-based interaction with virtual objects.

REFERENCES

[NJ03] M.Nakamura, L.Jones, "An Actuator for the Tactile Vest – a Torso-Based Haptic Device", Proceedings of HAPTICS'03, Los Angeles, CA, 2003, p. 333

[VPHS05] R.Velázquez, E.Pissaloux, M.Hafez, J.Szewczyk, "A Low-Cost Highly-Portable Tactile Display Based on Shape Memory Alloy Micro-Actuators", Proceedings of IEEE VECIMS'05, Giardini Naxos, Italy, 2005

[WPFH98] P.S.Wellmann, W.J.Peine, G.E.Favalora, R.D.Howe, "Mechanical Design and Control of a High Bandwidth Memory Alloy Tactile Display", Proceedings of 5th International Symposium on Experimental Robotics 1998, Berlin, Germany, 1998