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Tactile Navigation Display

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Abstract

The use of the tactile modality is not common in Human Computer Interaction. However, there may be good reasons to do so. For example in situations in which the visual sense is restricted (e.g., in virtual environments lacking a wide field of view, or for the visually handicapped persons), or overloaded (e.g., flying an airplane or driving in an unknown city). The lack of a wide visual field of view excludes the use of peripheral vision and may therefore degrade navigation, orientation, motion perception, and object detection. Tactile actuators applied to the torso, however, have a 360° horizontal 'field of touch', and may therefore be suited to compensate for the degraded visual information.

Keywords: Virtual Environment, tactile, cutaneous, haptic, navigation, orientation.

1 Introduction

This paper will specifically discuss the use of the tactile sense to supplement visual information in relation to navigating and orientating in a Virtual Environment (VE). Attention is paid to the potential advantages, the possible pitfalls, and the missing knowledge.
Virtual Reality (VR) technology allows the user to perceive and experience sensory contact with a non-physical world. A complete VE will provide this contact in all sensory modalities. However, developments in VR technology have mainly focussed on the visual sense. In the last decade, enormous improvements have been made regarding the speed and resolution of the image generators. However, the human senses are not restricted to the visual modality. Using the tactile modality as well in a VE might have several advantages; e.g., tactile information can enhance the immersion of the observer, guide movements, be a substitute for force feedback, and serve as a general information channel.

Rationale. Despite the current power of image generators, the field of view of VE visuals is still reduced compared to real life. This may degrade orientation and navigation performance in a VE. Because the tactile channel has a 360° field of touch, a tactile display may compensate for the lack of peripheral viewing. However, fundamental and applied knowledge is required for successful use of tactile displays for this specific application, and moreover, for successful development of devices. At this moment, not all this knowledge is available or applicable. Areas that deserve attention include:

- body loci other than hand and fingers,
- sensory congruency (see next paragraph),
- cross–modal interaction,
- perceptual illusions,
- attention.

Multi Modal Man Machine Interaction (M_4I) and Sensory Congruency. Effective behavior requires that stimulation from several sensory channels be coordinated and made congruent informationally as well as temporally [8]; knowledge of this congruency (or incongruency) is a prerequisite for the success of M_4I. Numerous examples show that information is not always perceived congruently by the different senses. For example, in the spatial domain, vision dominates touch (sometimes called visual capture [6], and found in e.g. estimating length and in perceived size [14], [17]), and touch dominates hearing ([9], [10], [19]). In the temporal domain, the perceived duration of a sound is longer than that of a light of equal length ([1], [4]), and intervals bounded by light flashes appear shorter than those bounded by brief auditory stimuli ([5], [18]). A similar incongruency is found in a simple experiment [21] on the perception of visual and tactile time intervals. The perception of open time intervals, either marked by visual stimuli (blinking squares on a monitor), or tactile stimuli (bursts of vibration on the fingertip with the same duration as the visual stimulus) was studied in uni– and cross–modal conditions. The results of the experiment showed a large bias in the cross–modal condition: tactile time intervals are overestimated by 30% compared to visual intervals (see Figure 1). This indicates that sensory congruency is a non–trivial aspect of integrating sensory modalities.

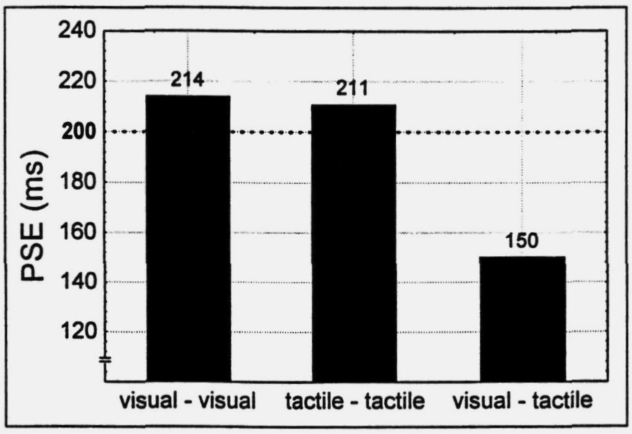

Fig. 1. Point of Subjective Equality (PSE) for a 200 ms standard open time interval. The visual – tactile condition shows that a 150 ms tactile interval is judged to be equal in length to a 200 ms visual interval.

2 Tactile Orientation and Navigation Display

The restricted field of view available for, amongst others, VE users, closed cockpit pilots, or the visually impaired, may degrade spatial orientation and navigation performance. In these situations presenting information via the tactile channel can support the observer. In the early nineties, two tactile naviagation displays for pilots were developed. Gilliland and Schlegel [3] conducted a serie of studies to explore the use of vibrotactile stimulation of the human head to inform a pilot of possible threats or other situations in the flight environment. The tactile display uses the pilot's head as display surface to provide an egocentric view of the environment, that pilots can rapidly relate to their cognitive maps and their orientations within them. The relative accuracy, which represents how close the subject came to designating the correct site, did deteriorate with increased numbers of stimulation sites. However, relative accuracy was reasonably good even with 12 stimulation sites (87%). In operational environments, a functional tactile information system may not require absolute accuracy if it supplies redundant information to enhance situation awareness, or merely alerts the operator to targets or threats. Rupert, Guedry and Rescke [12] developed a matrix of vibro–tactors that covers the torso of the pilot's body. This prototype may offer a means to continuously maintain spatial orientation by providing information about aircraft acceleration and direction of motion to the pilot. Rupert and associates studied the transmission of roll and pitch information by means of the tactile array. Within the pitch and roll limits of their torso display (15 and 45 deg, respectively), the subjects could position the simulated attitude of the aircraft by the tactile cues alone. The accuracy of pitch and roll was within 5 deg, after a learning period of 30 min.

A potential interesting body locus for a tactile navigation display is the torso because of its large surface, its 3D form, and its possible ego-centric 'view'.

Furthermore, information presented to the torso is not likely to interfere with tactile information presentation to, for example, the hands. A simple tactile display could consist of a number of actuators located in a horizontal plane. By stimulating a certain area, the display could indicate a direction, e.g., to a point or object of interest.

The first step in the development of the proposed application is cataloguing the relevant perceptual characteristics, i.e., the spatial and temporal information processing capacity of the torso. After this initial phase, the next step is to understand the perceptual biasses and use of navigation information presented on the torso, i.e. the usability aspects of the proposed display.

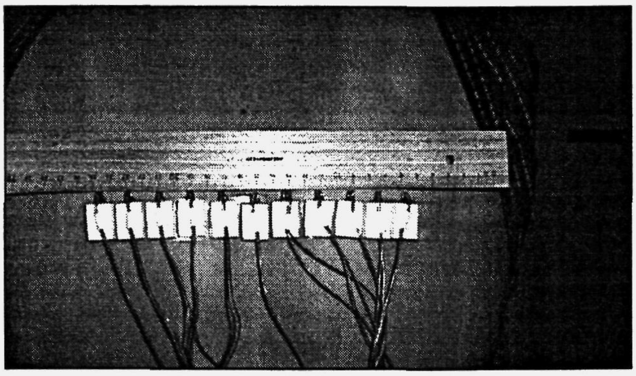

Fig. 2. Placement of the tactile actuators on the back for the spatial sensitivity experi ments (scale is cm).

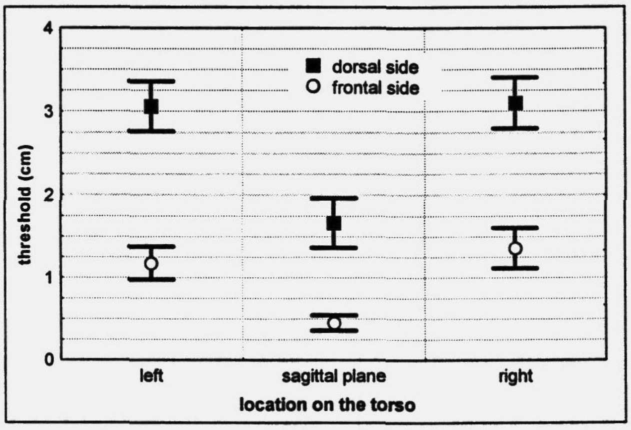

Fig. 3. Spatial accuracy of the torso for vibro–tactile stimuli. The threshold is the minimum (centre-to-centre) distance between two actuators needed to reach a 75% correct localisation performance.

2.1 Determining the Spatial Sensitivity of the Torso

Since only indirect data are available regarding the spatial resolution of the torso for vibro–tactile stimuli, basic research was needed to formulate the requirements for an optimal display configuration. On the one hand, one wants to use the full information processing capacity that is available; on the other hand, one wants to keep the number of actuators to a minimum. Therefore, a series of experiments was conducted in which the spatial resolution of the torso was determined (for the apparatus, see Figure 2, for details of the experiment, see [16]).

The results of the experiments showed that the sensitivity for vibro–tactile stimuli presented to the ventral part of the torso was larger than for stimuli presented to the dorsal part (see Figure 3). Furthermore, the sensitivity near the sagittal plane of the torso is larger than to the sides. Moreover, the sensitivity is larger than was expected on the basis of the existing psychophysical literature on two—point thresholds (e.g., see [7], [20]).

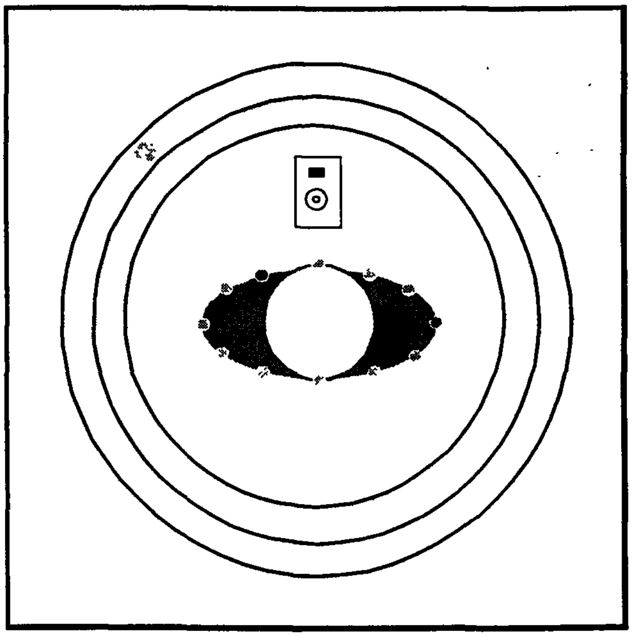

Fig. 4. Top view of the set-up for the direction discrimination task. With a dial, the observer can position a cursor (a spot of light projected from above) along a white circle drawn on the table. The cursor should be positioned such that it indicates the direction associated with the tactile stimulus.

2.2 Presenting Spatial Information on the Torso: Tactile Direction Discrimination

In a follow–up experiment, tactile actuators were attached around the participant's torso. The participant was seated in the centre of a table (see Figure 4) On this table, a white circle was painted, and the participant's task was to position a spot light (projected from above) on this circle such that it indicated the direction of the tactile stimulus (either one or two adjacent actuators were activated at a time).

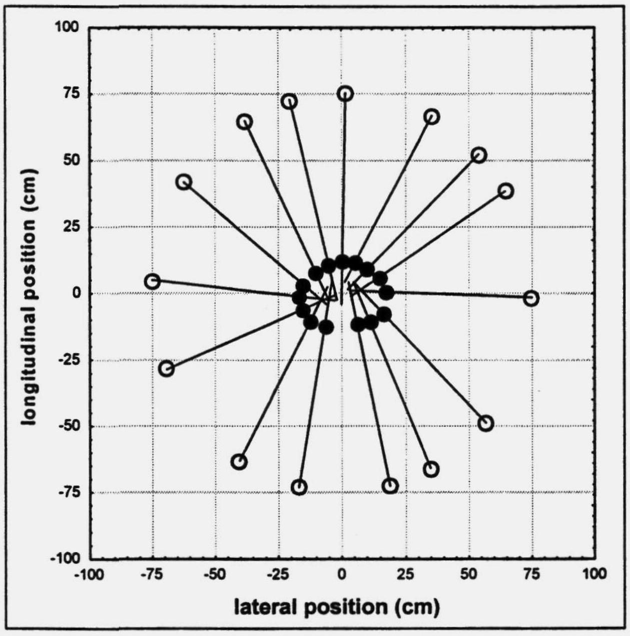

Fig. 5. Example of the mean responses (open circles) of one observer associated with the tactile stimulus on the torso (filled circles). The intersections of the lines connecting those points hint at the existence of two internal reference points.

The results of this experiment were interesting in several ways. First of all, none of the participants had any trouble with the task. This is noteworthy since a point stimulus does not contain any explicit direction information. The strategy people use is probably similar to the one known in visual perception, namely using a perceptual ego–centre as a second point. Several authors determined the visual ego–centre (e.g., [11]), that can be defined as the position in space at which a person experiences him or herself to be. Identifying an ego–centre or internal reference point is important, because it correlates physical space and phenomenal space. A second reason to determine the internal reference point in this tactile experiment was the striking bias that all participants showed in their responses, namely a bias towards the sagittal plane, see the open circles in Figure 5 for an example. This means that stimuli on the frontal side of the torso were perceived as directions coming from a point closer to the navel, and stimuli on the dorsal side of the torso were perceived as coming from a point closer to the spine. Further research [15] showed that this bias was not caused by the experimental set–up, the visual system, the subjective location of the stimuli, or other anomalies.

The most probable explanation is the existence of two internal reference points: one for the left side of the torso, and one for the right side. When these internal reference points are determined as a function of the body side stimulated, the left and right points are 6.2cm apart on average across the participants (see Figure 6). The third noteworthy observation is related to the variance of the responses as a function of the presented direction: performance in the front–sagittal region is very good with standard deviations between 4° and 8° (see Figure 7), and somewhat lower towards the sides.

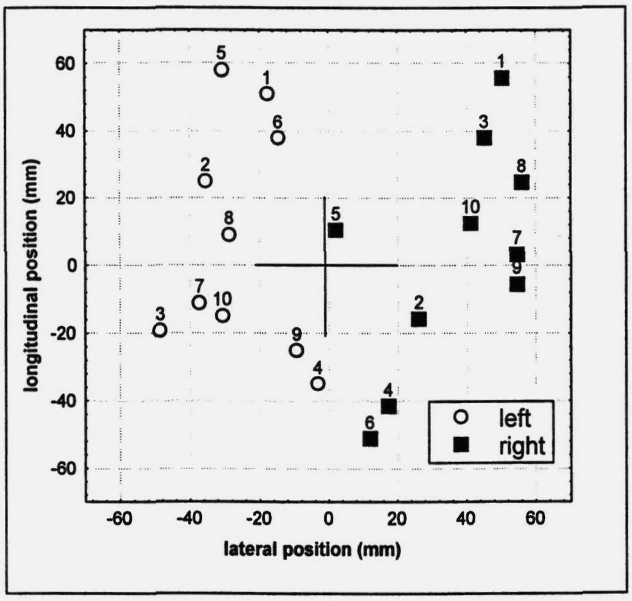

Fig. 6. The Internal Reference Points for the ten observers in the tactile direction determination task. The numbers indicate the individual observers.

More details on the experiments can be found in [15]. The most relevant implications for the application of tactile displays for spatial information are the following:

- observers can perceive a single tactile point stimulus as an indication of external direction,
- the consistency in the perceived direction varies with body location. Performance near the sagittal plane (SD of 4°) is almost as good as with a comparable visual display, but lowers toward the sides,

- direction indication presented by the illusion of apparent location (the percept of one point stimuli located in between two simultaneously presented stimuli) is as good as that of real points,
- small changes in the perceived direction can be evoked by presenting one point stimulus to the frontal side, and one to the dorsal side of the observer.

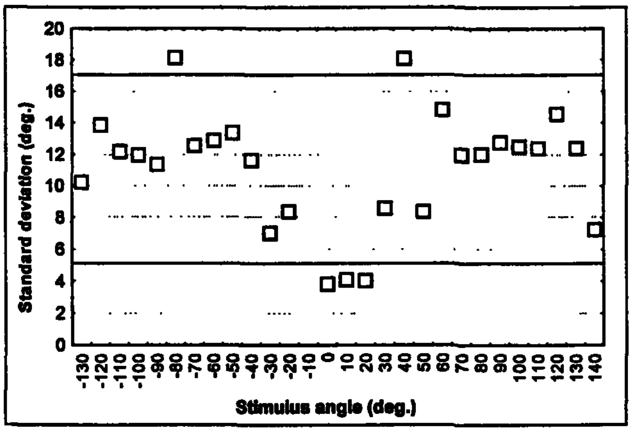

Fig. 7. Standard Deviation of the tactile responses as function of the stimulus angle (0° is the mid—sagittal plane with negative angles to the left). The horizontal lines summarize the results of a post hoc test; pairs of data points differ significantly when separated by the two lines.

3 Discussion

Some potentially beneficial applications of tactile displays in VE or HCI are presented in the Introduction. The present paper focussed on tactile information as supplement to degraded visual information, more specifically for navigation. After choosing what information the tactile display must be designed for to present, the relevant perceptual characteristics of the users must be determined. Although there is substantial literature on tactile perception, the available knowledge isn't by far as complete as on visual and auditive perception. Gaps in the required knowledge, e.g., on tactile perception of body loci other than the arms, hands, and fingers, must be filled before applications can be successful. Besides data on fundamental issues such as spatial and temporal resolution, perceptual illusions might be an interesting area in relation to display design. Illusions such as apparent position (which may double the spatial resolution of a display), and apparent motion (which allows to present the percept of a moving stimulus without moving the actuators) offer great opportunities to present information efficiently. Still more illusions are discovered (e.g., see [2]).

After cataloguing all relevant basic knowledge, specific applications must be studied to further optimise information presentation and display use. Another important point, which is not fully addressed in this paper, is the interaction between the sensory modalities.

As shown in this paper, sensory congruency and response biasses are of major interest in this respect. An enhanced Human Computer Interface will be multi–modal, but the interaction between the tactile and the other senses (e.g., regarding attention switching, see [13]) is an area that is only recently being addressed. Just adding tactile information without careful considerations does not automatically enhance the interface or improve the user's performance.

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