Enhancing Outdoor Navigation Systems through Vibrotactile Feedback

Dominik Bial
PALUNO – The Ruhr Institute for
Software Technology
University of Duisburg-Essen
Schuetzenbahn 70
Essen, 45117 Germany
dominik.bial@paluno.uni-due.de

Dagmar Kern
PALUNO – The Ruhr Institute for
Software Technology
University of Duisburg-Essen
Schuetzenbahn 70
Essen, 45117 Germany
dagmar.kern@paluno.uni-due.de

Florian Alt
PALUNO – The Ruhr Institute for
Software Technology
University of Duisburg-Essen
Schuetzenbahn 70
Essen, 45117 Germany
florian.alt@paluno.uni-due.de

Albrecht Schmidt
PALUNO – The Ruhr Institute for
Software Technology
University of Duisburg-Essen
Schuetzenbahn 70
Essen, 45117 Germany
albrecht.schmidt@paluno.uni-due.de

CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.
ACM 978-1-4503-0268-5/11/05.

Abstract

While driving many tasks compete for the attention of the user, mainly via the audio and visual channel. When designing systems depending upon providing feedback to users (e.g., navigation systems), it is a crucial prerequisite to minimize influence on and distraction from the driving task. This becomes even more important when designing systems for the use on motorbikes; space for output devices is scarce, as people are wearing helmets visual feedback is often difficult due to lighting conditions, and audio feedback is limited. In a first step we aimed at creating an understanding as to how information could be communicated in a meaningful way using vibrotactile signals. Therefore, we investigated suitable positions of actuators on the hand, appropriate length of the vibration stimulus, and different vibration patterns. We built a first prototype with 4 vibration actuators attached to the fingertips and asked 4 participants to test our prototype while driving. With this work we envision to lay the foundations for vibrotactile support in navigation systems.

Keywords

Tactile interfaces, navigation, non-visual interaction

ACM Classification Keywords

H5.2. User Interfaces: Haptic I/O

Introduction

When riding a motorbike the driving task requires a high degree of attention from the user at any time. Even though a lot of different information in the vicinity strives after the user's attention, it is essential to limit their impact on the driving task. Commercial navigation systems use predominantly visual or auditory channels to communicate with the driver. More recently, navigation systems using audio-visual output have also become available for pedestrians, bikes, and motorcycles. However, navigation systems for motorcyclists are often a mere adaptation of in-car navigation systems and do not take different user needs or environmental requirements into account. Conditions such as high background noise, direct exposure to sunlight, or increased user distraction while driving make interaction with such navigation systems still cumbersome and drastically influence their usability. One possible solution is to enhance the navigation process through vibrotactile support, e.g., in gloves. We see great value in communicating information using tactile actuators. Even though the information bandwidth achieved is very low, it is still useful for applications that communicate small amounts of information such as directional information.

In this paper we aim at understanding the potential of vibrotactile support for navigation systems that are integrated in gloves. The contribution of our work is twofold. First, we present a proof-of-concept, identifying suitable positions for actuators on the hand and possible vibration patterns. Second, we built a prototype integrated into gloves and report on qualitative findings from an initial study in the real world. Our results indicate that tactile feedback is suitable to enlarge the output space of current navigation systems based on simple feedback patterns (e.g., encoding the direction).

Related Work

Several research projects use vibration motors for pedestrian navigation. In the Gentle Guide project, Bosman et al. [1] showed that by mounting the vibration motors on the wrist of a person's hands, the directions left or right could be communicated in a very reliable way. Tsukada et al. [5] created the Active Belt using 8 different directions. Distance to the destination is presented by changing the pulse interval of vibration motors. Van Erp et al. [6] looked closer into the opportunities of distance coding using different vibration rhythms. There are further approaches as to how vibrotactile information systems could be used in cars, e.g., [2][7]. All these projects have one thing in common: the location of the actuator on the body is used as an indication of direction. In contrast, our work looks at a more dynamic presentation, providing directional information, enabling more flexibility in the actuator's position on the body.

Another example is the haptic back display (3-by-3 tactor array) [4], which offers means for displaying two-dimensional direction information. Tan et al. "investigated the intuitiveness and discriminability of a set of directional lines 'drawn' on the subjects' back using the sensory saltation phenomenon" [4]. Our approach is similar in that we use several actuators; yet, we focus on a 1-dimensional direction output and provide information to the user's hand. In Tacticycle [9, 10] actuators were placed in the steering rod of a bicycle to guide cyclists in unknown areas with tactile feedback. The vibration output is accompanied by visual information on a display.

Sahami at al. built a multi-vibration mobile phone and researched the recognition rate of vibration patterns at

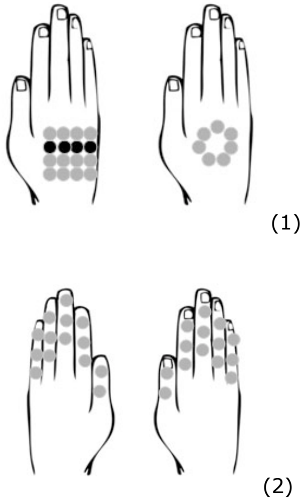

Figure 1. Arrangement of vibration actuators: (1) Back of the hand. Actuators can be arranged in a circle or matrix, allowing vertical / horizontal patterns. (2) Fingers. Actuators can be arranged on the fingers / thumbs or on the back of the hand.

the human hand [3]. They integrated 6 vibration actuators into the phone, and therefore, the position of the stimulus on the user's hand depended on how the user held the phone. In contrast, we assume fixed position of the actuators (e.g. as part of a glove or ring on one's finger, similar to [8]).

Vibrotactile Information at the Human Hand

The human hand offers a wide range of possible positions for vibration actuators: the fingers, the palm, and the back of the hand. The palm and the back of the hand are suitable for mounting vibration actuators in a circle or a matrix [4] (Figure 1.1). The fingers provide at least 6 different single positions for vibration actuators at each finger and four at the thumbs (Figure 1.2). Different directional vibration patterns can be used to indicate the direction in which the user should drive. Vibration of all actuators on the left or on the right side of the hand is the simplest direction pattern. A more complex vibration pattern is to give the user the impression that the vibration is moving over the hand. We call this *direction pattern* in the following. Therefore the vibration actuators are actuated one after another, optionally with a short pause in between. For example, a vibration signal could move from the left to the right side of the hand.

There are two different parameters that can be adjusted in a vibration signal to communicate distance to a destination: intensity and rhythm [6]. We adjust the vibration duration and the delay in order to indicate the remaining distance, e.g., to a turning point. We call this *distance pattern*. Hence, the speed at which the signal moves over the hand could increase, as the user gets closer to the destination, indicating both direction and distance at the same time.

User Study

To inform our design we conducted an initial lab study. We focused on providing rich vibrotactile information to one hand only without a concrete navigation task. We aimed at finding out about the best position for the vibration actuators, the recognition of directions and distance patterns. We recruited 14 participants (2 female). The average age was 26.9 (SD=5.2), and all participants were right-handed. The length of the experiment averaged 15-20 minutes.

Apparatus

Our apparatus to explore the design space consists of a microcontroller (PIC 18F252), 4 power drivers, 4 vibration motors and a Bluetooth communication module, similar to the hardware in [3]. An application running on the microcontroller receives commands from the serial line (BT) and controls the vibration motors using pulse-width modulation. We use mobile phone vibration actuators that are compatible with the Nokia 8800. The vibration actuators are integrated into short pieces of hook-and-loop tape, so that they can be easily attached to the desired position (Figure 2).

Study Design

To compare the different locations we used a linearly moving signal along the back of the hand, the palm, and along the fingertips. Figure 2 shows the arrangement of the vibration actuators for each position. Bosman et al. [1] found that lengths of pulse trains are easier to recognize than intensities. Hence, we decided to use this parameter for communicating distance. Additionally, the *distance pattern* were tested with different signal lengths and delays. We controlled each actuator's vibration duration, the pause time between two consecutive pulses at different actuators, and the num-

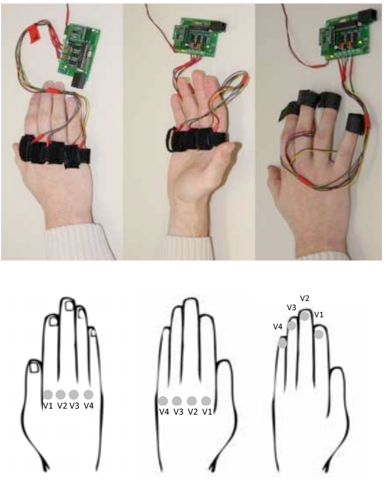

Figure 2. Vibration actuators mounted to the back, the palm and the fingertips of the right hand and their arrangement.

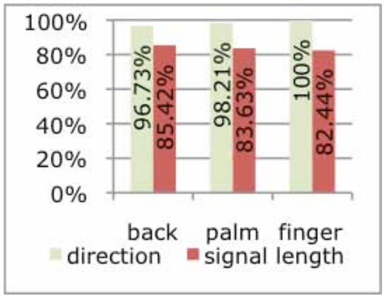

Figure 3. Recognition rate direction and signal lengths at the positions: back, palm and finger tips.

ber of moves from one direction to the other. To do so three different signal lengths were introduced: short (300ms-vibration time / 150ms-pause, see Figure 3), medium (600ms / 200ms), long (900ms / 250ms). We decided to let each signal move twice along the hand.

In the study we analyzed the three different positions of the vibration actuators, the direction pattern and the distance pattern. Hence, the participant's task was to recognize the direction and the length of the signals on the right hand. For each position, 24 different signals were presented to the user in random order - four signals for each length (short, medium, long) and in each direction (left, right). The study employed a within-subjects design, in which each subject performed the task in all conditions.

Procedure

After a brief introduction, the participant was asked to take off any rings to not influence the vibration. Then, the vibration actuators were placed either on the fingertips, the back, or the palm of the participant's right hand. In all conditions, the participant placed their palms on the table. We used a counterbalanced order for the position of the actuators. After each vibration signal, the participant told the experimenter direction and length of the signal (e.g., left – short).

Results

The recognition rate of *direction* was high for all positions. The participants achieved the best recognition (100%) when the actuators were placed on the fingertips. Results were better than on the palm (98.2%) and on the back (96.7%) of the hand.

Distinguishing the three different signal *lengths* (short, medium, long) was more difficult for the users. The short signal had the best recognition rate at each position. On the palm and the back of the hand, the recognition rate of the short signal was better than the other two lengths. On the fingertips, the recognition rate of the short signal was only better than the long signal.

In a questionnaire following the study, the participants were asked to rate the pleasantness of each position on a 5-Point Likert scale (1=not pleasant at all, 5=very pleasant). The fingertips were rated to be the most pleasant position ((fingertips, back), $p<0.05$, (fingertips, palm), $p<0.01$). 12 participants stated that they could feel the vibration best at the fingertips. Only 2 preferred the palm.

The participants were also asked to rate the difficulty in distinguishing signal lengths at each position (1=very difficult, 5=very easy). They found it significantly easier to recognize the signals at the fingertips compared to the other positions ((fingertips, back), $p<0.05$), ((fingertips, palm), $p<0.05$) and recognition on the palm of the hand was significantly better than on the back ((back, palm), $p<0.05$). Participants also rated how easy it was to distinguish between two consecutive signal lengths independent of the positions of the actuators (1=very difficult, 5=very easy). The signal lengths that the users found easiest to distinguish between were long and short ((long-short, long-medium), $p<0.01$, (long-short, medium-short), $p<0.05$). Medium-short was also easier distinguishable than medium-long (medium-short, medium-long), $p<0.01$).

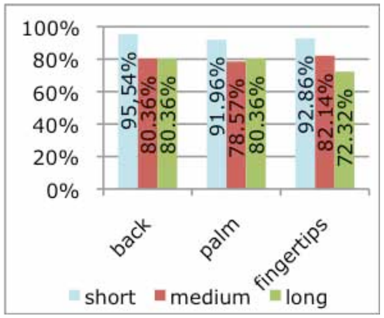

Figure 4. Recognition rate of signal lenghts short, medium and long at each position back, palm and fingertips.

Figure 5. Gloves with built-in actuators.

Prototype of a Navigation System in Gloves

In Figure 5 a prototype of a navigation system integrated into two gloves is shown. It consists, similar to the apparatus used in the study, of actuators located at each fingertip, a microcontroller, and a Bluetooth connection board. The findings of the study discussed above determined the positioning of the vibrotactile elements. Furthermore, we attached a mobile phone, which is used as a display, on the steering bar.

Study Design

To evaluate our prototype we recruited two participants riding a bicycle and two motorcyclists for testing the gloves under real driving conditions. As our initial study showed that direction patterns were significantly easier to recognize, we focused on direction only. The prototype was first tested by the cyclists to support the design before it was worn on a motorbike.

The participants had to test three different conditions:

- *Tactile*: The short vibration pattern was extended so that the direction was shown on both hands simultaneously. The signal went from left to right or right to left on each hand. Moreover, all actuators were switched on for 1.5 seconds before the actual short signal. This should indicate an upcoming pattern.
- *Visual*: During *visual* no other feedback was provided but an image with an arrow pointing left or right on the display. The arrow was shown for 8 seconds before it disappeared again.
- *Combined*: *Combined* made use of *tactile* and *visual*. First, an image with an arrow is shown. Then, after 2 seconds, *tactile* was started so that both signals could have been perceived at the same time. All in all, *combined* lasted for 8 seconds.

8 signals were sent so that the participants had to turn 4 times left and 4 times right for each of the conditions. The signals and conditions varied randomly.

Procedure

We chose the university's parking lot where the participants could drive without affecting the traffic and being endangered. First, the participant got a short introduction to the purpose of the study and the different conditions were explained. Afterwards, the participants had to drive along the lanes of the parking lot. At the end of each lane they had to turn left or right based on a signal we sent to our prototype. The experimenter noted whether the participants turned correctly. At the end the participants were debriefed and interviewed about their impressions, concerns, and further ideas.

Results and Participant's Feedback

During *combined* and *visual* none of the participants made a mistake and each turn was taken correctly. For the *tactile* condition only 87.4% (27/32) were correct.

The interview showed that all participants liked the idea to enhance navigation systems with vibrotactile feedback. When we asked the participants to rank the techniques all participants but one mentioned that *combined* was their preferred technique followed by *visual* and *tactile*. They found it sometimes complicated to distinguish between the signals while driving, but felt, that it was a great idea to support the visual output of current navigation systems. Therefore, *combined* was their preferred technique. All participants stated that *visual* caused them to look on the display more often while *tactile* was considered to be more exhausting as more concentration was needed.

All participants, especially the motorcyclists, showed great interest in using and purchasing such a system. Both motorcyclists stated that they used a navigation system on their motorbike before, but experienced problems with audio feedback and lighting conditions while driving. Both actually stopped using sound and, therefore, it was common to miss an intersection. Driving noise makes it impossible to understand audio signals and wearing headphones below a helmet was mentioned to be painful. Moreover, when using headphones it is not possible to wear earplugs anymore.

Discussion and Conclusion

In this paper we investigated opportunities for presenting navigation information (direction and distance to a destination) using vibration actuators at the user's hand. We built a prototype with four vibration actuators to be mounted either on the back or the palm of the hand or at the fingertips. Our initial study revealed that the fingertips are the most sensitive position. The results show that it is difficult for people to distinguish between three signal lengths. Yet, distinguishing between two different signal lengths seems promising.

Testing under real driving conditions showed, that there are minor problems regarding the patterns we explored in our first settings, but participants were able to distinguish signals in most cases. Using tactile feedback to enlarge the output space of current navigation systems and to support visual signals seems to be promising.

In future research, we will focus on a more thorough evaluation of our idea. We are interested whether vibrotactile navigation is better suited for real navigation tasks than current approaches and in the benefits compared to traditional visual presentation regarding driver distraction. Additionally, we aim at further investigating the design space of using tactile feedback with motorcycling (e.g., integration of actuators in different parts of the motorcyclists' suits).

References

[1] Bosman, S., Groenendaal, B., Findlater, J. W., Visser, T., de Graaf, M. and Markopoulos, P.: Gentleguide: An exploration of haptic output for pedestrian guidance, Proc. Mobile HCI*, 2003.*

[2] Ho, C., Tan, H. Z., Spence, C., Using spatial vibrotactile cues to direct visual attention in driving scenes. Transportation Research Part F: Traffic Psychology & Behaviour, 8, 397-412, 2005.

[3] Sahami, A., Holleis, P., Schmidt, A., Häkkilä, J. Rich Tactile Output on Mobile Devices. Proc. AmI 2008.

[4] Tan, H. Z., Gray, R., Young, J. J., Traylor, R. (2003). A haptic back display for attentional and directional cueing. Haptics-e: The Electronic Journal of Haptic Research, 1(3).

[5] Tsukada, K., Yasumura, M.: ActiveBelt: Belt-Type Wearable Tactile Display for Directional Navigation. Proc. of Ubicomp, 2004.

[6] Van Erp, J. B. F., Van Veen, H. A. H. C., Jansen, C., Dobbins, T., Waypoint navigation with a vibrotactile waist belt. *ACM Transactions on Applied Perception, 2,* 106–117, 2005.

[7] Van Erp, J.B.F., Van Veen, H.A.H.C., Vibro-Tactile Information Presentation in Automobiles. Proc Eurohaptics, 2001.

[8] Werner, J., Wettach, R., Hornecker, E., United-pulse: Feeling your partner's pulse. *Proc Mobile HCI 08.*

[9] Poppinga, B., Pielot, M., Boll, S., Tacticycle – A Tactile Display for Supporting Tourists on a Bicycle Trip. *Proc Mobile HCI 09.*

[10] Pielot, M., Poppinga, B., Boll, S., Understanding tourists on a bicycle trip "in the wild". *Proc Mobile HCI 09.*