Augmenting spatial awareness with Haptic Radar

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Abstract

We are developing a modular electronic device to allow users to perceive and respond simultaneously to multiple spatial information sources using haptic stimulus. Each module of this wearable "haptic radar" acts as an artificial hair capable of sensing obstacles, measuring their range and transducing this information as a vibro-tactile cue on the skin directly beneath the module.

Our first prototype (a headband) provides the wearer with 360 degrees of spatial awareness thanks to invisible, insect-like antennas. During a proof-of-principle experiment, a significant proportion (87%, p=$1.26 * 10^{-5}$*) of participants moved to avoid an unseen object approaching from behind without any previous training. Participants reported the system as more of a help, easy, and intuitive.*

Among the numerous potential applications of this interface are electronic travel aids and visual prosthetics for the blind, augmentation of spatial awareness in hazardous working environments, as well as enhanced obstacle awareness for motorcycle or car drivers (in this case the sensors may cover the surface of the car).

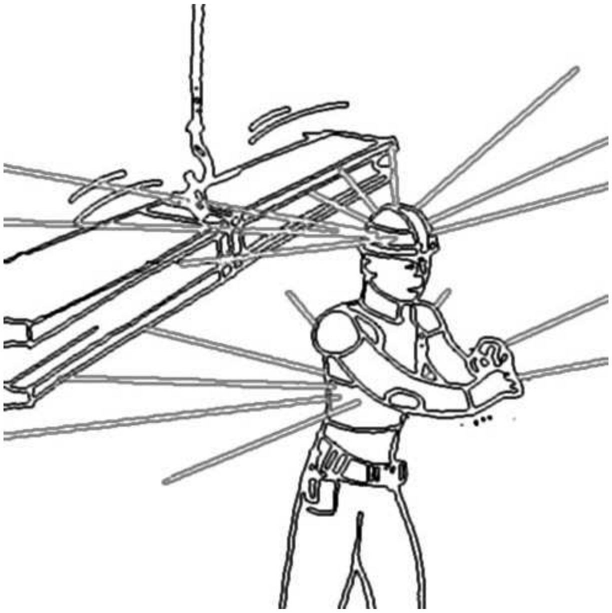

Figure 1. Augmented spatial awareness with an artificially extended skin.

1 Introduction

This project extends existing research on Electronic Travel Aids (ETAs) relying on tactile-visual sensory substitution (TVSS) for the visually impaired. Keeping things simple, we can say that two different paths have been explored in the past. One consists in extending the capabilities of the cane for the blind (using ultrasound or even laser range-finders) and converting the sensed range-data to a vibro-tactile cue on the hand (see for example [13], [2]). The other approach uses the input from an imaging device to drive a two-dimensional haptic display placed on the skin [6] or even on the tongue [1]. This approach benefits from the research on reading aids based on TVSS [11].

Each has its own advantages and disadvantages. For instance, the "image-mapped-to-the-skin" is very promising because it potentially provides the user with an extremely rich source of information. However, it may not be as efficient as it seems at first glance: although the brain has a certain degree of high-level cognitive cross-modal plasticity [9], the withdrawal reflex in reaction to a sudden skin stimuli will remain active. In other words, even a trained participant (able to "see with the skin") may not be capable of shutting down this somatic reflex arc. More importantly, since stereoscopic vision is not simple to achieve through this method, the approach does not provides any intuitive spatial (depth) cue.

On the other hand, the white-cane aid is extremely intuitive precisely because it is not really a sensory-substitution approach: the cane only extends the reach of the user hand. But still, the traditional white cane (as well as more or less sophisticated ETAs based on the same "extension of the hand" paradigm such as the Laser Cane [2] or the MiniGuide ultrasonic aid [8]) only provides spatial awareness in the direction pointed by the device. The users must therefore actively scan their surroundings. This process is inherently sequential, and as a consequence broad spatial awareness relies heavily on memory and on the user's ability to mentally reconstruct their surroundings, potentially overloading cognitive functions. The users must scan the environment as a sighted people would do with a flashlight in a dark room. The result is fragmented spatial awareness with a very low temporal resolution or "tunnel vision". In certain cases this approach may be sufficient, for instance when tracking a signed path on the floor. Some researchers have proposed an interesting way to overcome this resource-consuming scanning by using an automated scanner and converting the temporal stream of range-data to a modulated audio wave [7], [3]. However, this is not an ideal solution, because (1) the user must be trained to interpret the sound-scape in order to de-multiplex the temporal data into spatial cues, and (2) the device is cognitively obtrusive since it may distract people from naturally processing the other sounds.

1.1. The spatially extended skin paradigm

The haptic-radar project intends filling the gap between the two different approaches described above, while trying to retain the most interesting aspects of each. This is realized thanks to the following paradigm:

- **Modularity (or parallelism)**. The system is composed of several identical modules, thus exploiting the input parallelism of the skin organ.
- **Range-to-tactile translation**. Each module behaves as a "mini-cane" (or artificial hair or antenna) that translates depth-range information into a tactile cue right behind the sensor.

Actually, depending on the number and relative placement of the modules, this device can be seen as either an enhancement of the white cane approach (when just using a single module carried on the hand) or as a variation of the more classic "image on the skin" TVSS (when a large quantity of sensors are placed on the same skin region). It is a variation of the later approach, because instead of luminance-pixels we have *depth*-pixels and additionally the range data does not come from a raster-scan laser range-finder, but instead each measurement is independently performed at the module site. The user relies on spatial proprioception to give meaning to the tactile cues.

The driving intuition here is that tactile perception and spatial information are closely related in our cognitive system for evolutionary reasons: an analogy for our artificial sensory system in the animal world would be the cellular cilia, insect antennae, as well as the specialized sensory hairs of mammalian whiskers. There is evidence that insects can very rapidly use flagellar information to avoid collisions [4]. We then speculate that, at least for certain applications (such as clear path finding and collision avoidance), the utility and efficiency of this type of sensory substitution may be far greater than what what we can expect of more classical TVSS systems.

2. Headband Hardware Prototype

The prototype presented here is configured as a headband, which provides the wearer with 360 degrees of spatial awareness. Each module contains an infrared proximity sensor (SHARP GP2D12) with a maximum range of 80 cm (giving the user a relatively short sphere of awareness - everything at arm range). Vibro-tactile stimulation is achieved using vibration motors (Chongqing Linglong Electronic Mobile Phone Vibrator Motor C1226-56L28). This off-weight coin motor rotates at 9,000 RPM. Tactile cues are created by varying motor voltage input and consequently the speed of the rotation in direct proportion to the range-finder output. Objects that are closer to the range-finder produce more intense vibrations.

An ATMEGA128 micro-controller addresses the modules sequentially, and information is communicated to a PC for monitoring (using the Wiring and Processing environments [10]). The GP2D12 proximity sensors have a maximum sampling rate of about 5ms, so our interface is limited to a sampling rate of around 200Hz.

The proximity sensor and vibration motors were chosen based on cost and availability. Off-the-shelf components that were inexpensive were favored for this initial prototype. Currently, we are experimenting with other varieties of sensors (such as ultrasound) and intend to perform comparative experiments.

3. Proof-of-Principle Experiment

In a hazardous working environment such as a noisy construction site, one potential danger is being struck by an object that isn't seen or heard. For a pilot experiment, we decided to roughly simulate this by measuring how well individuals avoided objects approaching *from behind* in a somewhat safer and more controlled environment. For that purpose, we reconfigured the system by arranging most of the headband modules towards the back of the head.

We hypothesized that participants using this Haptic Radar prototype could avoid an unseen object approaching from behind. The purpose of this proof-of-principle experiment was to asses the performance of haptic feedback provided on the skin directly beneath the range finding sensors. In this first experiment, we did not study if the stimulus provided by the system was more or less efficient at producing a startling reflex or a conscious response by the user. Additionally, we wondered if participants who were not trained in how the Haptic Radar operates could intuitively avoid objects.

3.1. Participants

There were N=10 participants in our experiment. The participants were volunteers recruited from our laboratory. Participants were not randomly selected. However, the participants were not aware of the device and its purpose before the experiment.

The mean age of participants was 25.9 with a standard deviation of 4.51. With respect to gender 2 of 10 participants were female while 8 of 10 were male. All participants were Japanese individuals. All participants reported a college education. No reward was provided for participation. Instead we informally asked participants to help us with our research.

3.2. Apparatus

The experiment made use of a prototype system described above with 6 active modules at 30 degree increments roughly spanning 180 degrees along a flexible headband. The sensors were oriented along the back of the participant's head (situated in the region of the Parietal and Occipital skull bones). A simple Python [12] program was used to randomly determine which angles the stimulus would approach from. Two video cameras were used to film participant's responses to the stimulus.

A Styrofoam sphere approximately 12 centimeters in diameter impaled on a wooden rod approximately 1 meter long was used as the "unseen object." A blindfold was used to ensure that participants would not be aware of the approaching stimulus. A coin was used to randomly select task ordering. The experiment took place in a typical office equipped with a couch.

3.3. Design

The experiment consisted of two randomly ordered tasks. These tasks represented the independent variable. In the treatment task, participants used the Haptic Radar device. In contrast, during the control task the Haptic Radar device was switched off, but still worn.

As for the dependent variables we observed whether participants moved or succeeded in avoiding the stimulus approaching from behind. Additionally, we collected Likert-scale questionnaire data regarding the system's usability and demographic data.

3.4. Procedure

Participants were first welcomed to the experiment. They were asked to seat themselves and make themselves comfortable. Participants were then told that "the purpose of the experiment will be to test a system for avoiding unseen objects." They were further told that their goal in the experiment "will be to avoid an object approaching from behind." Participants were verbally asked if they understood the instructions. If they did not, in some cases the instructions were informally translated into Japanese.

Figure 2. Avoiding an unseen object

Following this we flipped a coin to determine whether participants would perform the treatment or control task first. After noting the task ordering, participants were handed a blindfold and asked to put it on. After the participant placed the blindfold over their eyes we would next place the Haptic Radar device on their head.

In the case that participants were assigned to perform the treatment task, we would then activate the Haptic Radar device. After programmatically generating a random ordering of angles, we moved the stimulus toward blindfolded participants' heads from each of the angles (240, 270, and 300 degrees, shuffled). Two performance measures were recorded: (α) the participant's movement in response to the stimulus and (β) the participant's success in completely avoiding the stimulus. (Note that the first performance measure (α) is similar but easier than the second measure (β)). In the case that participants were assigned to perform the control task the procedure was identical to the above, except that the Haptic Radar device was not activated. Having completed one task the process was repeated for the other condition.

Afterward participants were asked to fill out a questionnaire. The questionnaire collected demographic information (age, gender, nationality, education) and asked participants on an 8-point Likert scale the following questions: "For avoiding the object the system is a: (Help...Hindrance)," "Using the system is: (Difficult...Easy)," "The system is: (Intuitive...Confusing)," "The system is: (Uncomfortable...Comfortable)." We also conducted very informal interviews to get a sense of participant's attitudes about the system and experience.

3.5. Results

On the first performance measure (α) movement in response of the stimulus, 26 out of 30 trials participants were successful. A simple proportion test confirms that this is a significant proportion (p=$1.26 * 10^{-5}$). On the second performance measure (β) completely avoiding the stimulus, the majority (18 of 30) of trials resulted in the participant avoiding the object completely, however this proportion is not significant.

A Wilcox test comparing against a hypothetical even split of opinion found that participants viewed the system as more of a help (p=0.005), easy (p=0.005), and intuitive (p=0.005). However opinions about the comfort of the system were more neutral with a mean of 5.2 and a standard deviation of 2.25 (where 1 is uncomfortable and 8 is comfortable).

3.6. Discussion

While the results are certainly promising it is healthy to view them with a certain degree of skepticism. Firstly, since the participants were non-randomly selected co-workers one might suspect an exaggerated desire not to provide negative feedback. Much of the questionnaire data should be viewed in this light.

It is also interesting to critically consider the effect of running an experiment with blindfolded participants. There is some evidence that visual processing dominates the processing of haptic data [5]. It would be interesting to compare the performance of participants when visual attention is occupied with the blindfolded participant's data.

In actuality this proof-of-principle experiment raises more questions than it answers: Can participants tell if an object will eventually collide with them? Furthermore, how do they perceive trajectory of approaching objects? Can participants navigate through a crowd or crowded environment? Do wearers become habituated to the vibrations? We hope in future work to address these questions and also to increase the realism of the experiment by having people use the device in an uncontrolled environment.

4. Conclusion

These preliminary results suggest that the Haptic Radar device can be successfully used to cause untrained users move in response to an unseen object approaching from behind. Video of Haptic Radar may be viewed at: http://www.k2.t.u-tokyo.ac.jp/fusion/HapticRadar/

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