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Thermal Imaging Aid for the Blind

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***Abstract*—To explore the efficacy of using a far infrared thermal camera with a haptic display to assist blind people in identifying humans, we performed experiments with a prototype device on five low-vision (functionally blind) subjects. Infrared allows for easy detection of human shape due to typically high contrast in temperatures from a person against their surrounding environment. Infrared cameras can be made small and inexpensive with uncooled microbolometer technology. Our study showed a great willingness by the blind subjects to use such a device after a short training session and both successful and unsuccessful operation. Future work will further develop the technology and undertake more expansive testing.**

I. Introduction

THE National Institutes of Health estimate that 120,000 Americans are blind, either totally or with light perception only. A smaller group, on the order of 20,000, has severe hearing and vision impairments and relies on tactile information almost exclusively to interact with the world around them. The idea of taking a normal-light visual image and presenting it to a blind person with a haptic interface has been explored for over three decades. These explorations have not resulted in significant gains due to the inherent complexity of converting real world visible image information into meaningful haptic information that can be quickly processed by a user. Generally, only the simplest images can be successfully communicated on a haptic display. Simple criteria, such as light intensity or color information, can not be used to identify the presence of people who are often the most important elements in a scene. It is generally accepted that tactually rendering all the information in a visible-light image leads to an overly cluttered, un-interpretable tactile representation [1]. Sophisticated image processing can help identify the presence of people, but realizing a low-cost, unobtrusive device based on complex processing is a significant impediment.

This paper evaluates the efficacy of using far infrared thermal imaging with a haptic display to simplify the problem of quickly identifying the presence and location of people relative to a blind user. The idea is to use a haptic display that images the output of an infrared camera. Each pixel of the display is a binary up or down determined by comparing the IR camera output to a threshold set just below human skin temperature. A prototype device was constructed consisting of a 50x50 tactile array from KGS Corp. and an infrared camera mounted in a textbook-sized frame as seen in Fig. 1. The frame can be held and aimed at a target with hand straps on each side. The prototype device also attaches, via a tether, to a notebook computer. The device was tested by five blind users to establish the efficacy of the system in a variety of real world scenarios.

Fig. 1. Prototype device in hand held mode. The infrared camera is mounted on top of the tactile display. The tactile display shows the image of two people in front of the user.

II. Test Methodology

The objective of human performance testing was to determine the capabilities of a blind or severely visually impaired user to identify the locations and movements of people by using the prototype thermal tactile device. First the subjects were trained on general use of the prototype device. Following the training, two groups of tests were performed. One group involved identifying situations with a single person being observed by the blind subject (hereafter the observed person is referred to as a single model-subject). The other group involved multiple people being observed and (hereafter referred to as multiple model-subjects). Measurements of task performance time and task error rates were the key assessment parameters.

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A. Subjects

There were 5 subjects recruited for this testing, all with little or no remaining vision. They were at most able to recognize hand movements at less than one foot. The subjects were purposely chosen to be adventitiously blind and therefore not lifelong cane or Braille users. All of the subjects were familiar with Braille, but only one (hereafter named KT) was a frequent Braille user. Since they all are adventitiously blind, they have all had the experience of visual imagery which may or may not be helpful in forming mental images based on tactile information.

B. Training

Before the testing began, there was a training session that lasted nominally a half hour. It was verified that each subject was unable to visually locate a person sitting at a conference table 10 feet away. The training session was for demonstrating general use of the device and explaining how the device works. The subjects familiarized themselves with the prototype in terms of the handgrips, tactile panel, location and orientation of the camera, etc. They were also given a brief explanation of its operation and response properties. Finally they were allowed to perform a short series of explorations of a single person acting as a model. The training session continued until the subject to could reliably locate the head of the single person model subject in two different tactile modes, static mode and scanning mode.

1) Static mode: In static mode, the camera and display are placed in a stationary position on a table in front of the subject. In this mode, the subject uses the tactile array as a full two-dimensional display by running the fingers of one hand across the array while steadying the device with the other hand.

2) Scanning mode: In scanning mode, the subject holds the device with both hands, spreading fingers of the dominant hand over the 3-4 columns of tactors closest to the edge of the display. The subject then scans the prototype device side to side to bring the section of interest in the image within the tactile range covered by the fingers. The scanning mode limits the subject's momentary field of "view" to a vertical strip of approximately 5°x25° angle and elevation space, but widens the total field of view reachable by scanning the whole device in any direction.

C. Single model-subject tests

The single model-subject tests involve the blind subject observing a single model-subject through the prototype device. The single model-subject tests were performed by the blind subjects using both static and scanning tactile modes. The blind subjects were asked to perform a number of explorations and tests listed in Table I. The subject was required to perform 6 exploration tasks as practice, followed by 6 tests in the same setting and mode. In each test, the subject had to determine which of the model subject's hand or hands were raised. The testing started with static mode and was followed by scanning mode. This order of mode testing was followed throughout the testing because the scanning mode was considered to be more difficult by the experimenters. The time to provide the correct answer in the 6 test cases was recorded. After the single model-subject session the subjects took a short break before starting the multiple model-subjects session.

TABLE I
LIST OF SINGLE MODEL-SUBJECT TESTS

• Find head	• Count/locate raised hand(s) L
• Find arm	• Count/locate raised hand(s) L
• Find raised arm	• Count/locate raised hand(s) LR
• Detect bent arm	• Count/locate raised hand(s) R
• Detect waving arm	• Count/locate raised hand(s) LR
• Detect waving hand	• Count/locate raised hand(s) R

D. Multiple model-subject tests

In the multiple model-subjects session only scanning mode was used. Static mode was not used in multiple model-subject tests because the camera angle (35 degrees) was not enough to cover the entire scene (80 degrees). The scene consisted of a room, defined in advance, with a conference table and a number of chairs. The layout was in a T configuration, where the table was the crossbar of the T. The subject stood about 10 feet from the table at the bottom position of the T. The region was defined to keep the subject from improperly including the nearby investigators as unintended model-subjects in the study. The boundaries were marked with glass coffee pots filled with water heated to body temperature. The boundary markers were at the ends of the crossbar of the T and the subjects sat along the length of the crossbar at the table. The subject stood at the bottom of the T and could swing left and right to scan the table. The subject would scan and virtually 'bump' in to the pots when the angle of scan reached a boundary limit. Occasionally, a subject would overshoot the predefined boundary of the region, which was corrected if the subject did not realize the error within a few seconds.

The multiple model-subject session had two parts. The first was to estimate the position of a subject sitting in one of the chairs as a proportion of the distance between the boundary markers. The second part was to identify the number and placement of subjects sitting in the 4 chairs. The subjects were told that there were 4 chairs only after the position estimating portion. The time to correctly answer the location tests was recorded. The list of tests performed in this session is shown in Table II.

TABLE II

LIST OF MULTIPLE MODEL-SUBJECT TESTS

• Locate 1 person (chair 2)	• Locate 1 person (chair 2)
• Estimate location in % L-R (chair 1)	• Locate 3 people (chairs 2,3,4)
• Estimate location in % L-R (chair 1)	• Locate 2 people (chairs 1,4)
• Estimate location in % L-R (chair 1)	• Locate 3 people (chairs 1,2,4)
• Count 2 people (chairs 1,3)	• Locate 2 people (chairs 2,4)
• Count 2 people (chairs 2,3)	• Locate 2 people (chairs 3,4)
• Count 3 people (chairs 1,2,4)	• Locate 3 people (chairs 1,2,3)
• Count 2 people (chairs 1,3)	• Locate 2 people (chairs 2,3)
	• Locate 2 people (chairs 1,2)
	• Locate 3 people (chairs 1,3,4)

III. RESULTS

All 5 subjects readily grasped the concept of the tactile display and its representation of objects and persons on the basis of temperature rather than light properties. They also had little trouble feeling the tactile display, and the contour of the model in the static mode. Consequently, the orientations and tests in this mode were uneventful for all subjects. When changing to scanning mode, four subjects managed, within 5-10 minutes of practice, to keep their fingers stationary and rotate the device to move the image under their stationary fingers to construct a mental model of the scene. The remaining subject, however, would scan the device, but then stop as soon as his fingers met the edge of an "object" and switch back to exploring the display with his fingers, effectively reverting to static mode; this same subject also repeatedly confused up-down and left-right orientations in the image. Over time, it became apparent that this subject, contrary to the remaining four, was unable to internalize the tactile representation as an image of the scene. After well over an hour, having concluded only a few tests in the scanning mode, testing with this subject was terminated, since we felt that all information he obtained was effectively static rather than scanned, and therefore uninformative as to his eventual ability to gain information from a few columns of moving dots. This subject was frustrated and convinced that with more practice he could learn the technique. The remaining 4 subjects, with more or less trial and error, were able to internalize the scene in both static and scanning modes, as could be ascertained from their remarks regarding details in the image and their relative and absolute locations. Subject KT stood out. He became proficient in use of the device in a very limited amount of time, apparently visualizing the scene in front of him in both modes. For this reason, we have plotted his results separately from those of the other subjects.

Subjects made very few errors once the testing started, but were rather reluctant to give an answer until they were confident it was correct. Of the 4 successful subjects, two made only one error (scanning mode, single model-subject), one made 3, and one 4. All other errors were made during single person scanning, and involved missing a raised hand, or reversing right and left, as the model faced the subject.

Fig. 2 provides timing results for the single model-subject session, comparing results for the static and scanning modes. Fig. 3 shows timing data for the multiple model-subjects session in scanning mode only; a logarithmic time scale was used for the single model test data because the range of results was quite wide.

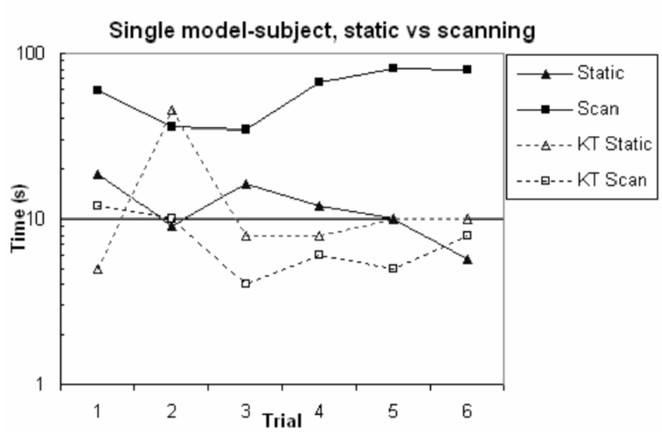

Fig. 2. Single model-subject testing time to correct response. Results are broken down into static vs. scanning and subject KT's results are separate.

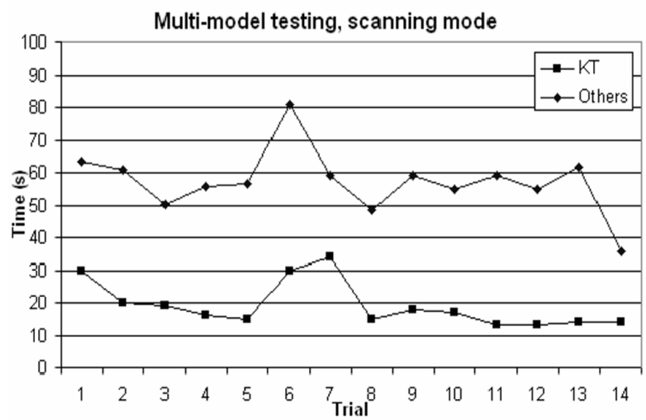

Fig. 3. Multiple model-subject testing time to correct response. KT's results are separate.

In the static mode, performance for all 4 subjects was similar, and a gradual improvement from trial to trial is seen, by approximately a factor of 4 over only 6 trials. In the scanning mode, KT performs as well as in static mode almost immediately, and even more quickly after one trial, showing that for this subject learning readily transferred from static to scanning mode. This does not appear to be true for the other three subjects, who require much more time in this mode, and whose performance does not noticeably improve over the 6 trials. In the multiple model-subjects trials, KT is again considerably faster than the other 3 subjects, but their performance slowly improves with experience; note that all subjects seem to require more time for a few trials after switching from counting to localizing, especially with multiple model-subjects (starting with trial 6).

IV. DISCUSSION

Four of five subjects were capable of learning to use the prototype in both modes, over the course of a 90 minute session, and would probably improve further with practice. Scanning mode was more difficult for these subjects than static mode, but the concept of tactile mapping was grasped in either mode. They are probably representative for the population of potential users of this haptic thermal imaging display, but so are the two outliers in our tests: one who has difficulty quickly grasping the mental representation of a tactile map, and who may or may not learn those concepts with practice, but who is unlikely to become a comfortable user; and one who almost intuitively grasps the concepts, and apparently combines his skills as a Braille reader and his ability to construct an accurate mental representation of the world from limited spatiotemporal information.

We conclude that a limited haptic thermal display with only 3-4 columns, in scanning mode, can be successfully used by most blind individuals. Some of these may require initial practice with a wider tactile image in static mode prior to being exposed to a narrower display that relies on scanning only. Experiences with other technologies requiring mental integration of spatial information, such as the white cane and Braille, are likely to be helpful in the learning process

The subjects were uniformly fascinated by the device and 4 of 5 were able to use it in its most advanced mode to identify the locations and activities of test subjects. It is difficult at this stage to predict objectively the true utility to a blind person of being able to scan and sense the location of people in a classroom, public venue, stage performance, etc. Even the potential availability of this information in a hand-portable device was inconceivable to all of our subjects prior to the experimental sessions. They all left with a strong desire to bring a portable device into the world where they could master its use and experiment with its impact.

V. FUTURE WORK

Future work will involve making a portable device that can be utilized in scanning mode. The device will incorporate a tiny, low cost infrared camera based on microbolometer technology. It will be hand held as shown in the concept drawing in Fig. 4. There will be a thumb control on the back to adjust the threshold for the tactile display. With this device future studies will take place to include a broad representation of blind individuals with different experience and skill levels to acquire a good estimate of the range of potential users of this technology.

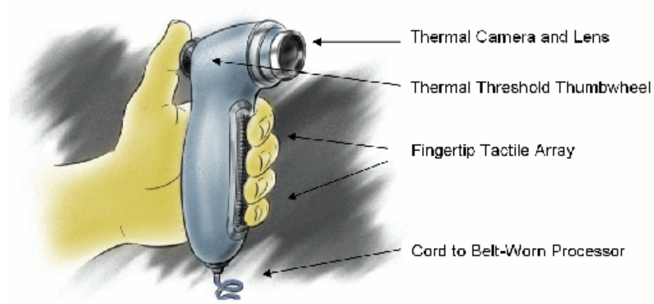

Fig. 4. Future hand held device with integrated miniature microbolometer based infrared camera and fingertip tactile array. The device will also include a thermal threshold thumbwheel. The battery and processor will be in a small belt worn box attached via a cord.

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[1] J. M. Loomis and S. J. Lederman, "Tactual perception," in Handbook of perception and human performance, vol. 2, 1986, ch. 31.