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# CDI-Type II: Collaborative Research: Cyber Enhancement of Spatial Cognition for the Visually Impaired

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## Preview of Award 0835689 - Final Project Report

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### Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	0835689
Project Title:	CDI-Type II: Collaborative Research: Cyber Enhancement of Spatial Cognition for the Visually Impaired
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Recipient Organization:	University of Maine
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Submission Date:	12/04/2013
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Nicholas Giudice

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### Accomplishments

#### \* What are the major goals of the project?

This final project report summarizes the progress made by the University of Maine Co-PI Giudice on NSF supported research on Award Number CDI-0835689, entitled CDI-Type II: Cyber Enhancement of Spatial Cognition for the Visually Impaired.

The overarching goal of this project was to research the information requirements and optimal interface design needed for a non-visual Cyber Assistant to aid indoor spatial learning and navigation for blind and low-vision people. A critical component of this project involved conducting a series of behavioral studies with human participants. The overall goals of these studies are as follows (with each building on the previous theme):

- 1) Isolate the environmental characteristics that need to be conveyed to a user to facilitate accurate spatial knowledge acquisition and wayfinding behavior.
- 2) Determine the perceptual and cognitive factors that promote optimal learning and understanding of this environmental information.
- 3) Specify and design the best non-visual interface for the system based on these key human factors.
- 4) Empirically evaluate behavioral performance and assess usability parameters with the developed system for supporting environmental learning and navigation tasks, or general spatial cognition behaviors (or design prototypes for these purposes using virtual reality as a test bed).
- 5) Use the experimental results to provide a feedback loop for guidance on subsequent experiments and interface design, as well as to guide the technical development of sensors and computer vision algorithms being developed by other members of our project team.

**\* What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities:

In order to accomplish these goals, the major research activities on this project at the University of Maine in Dr. Giudice's Virtual Environment and Multimodal Interaction (VEMI) lab can be separated into two distinct lines of research: (1) work on spatialized audio information processing and interface development and (2) work on information processing using vibro-tactile stimuli and development of a new interface to provide non-visual access to spatial graphics (figures and maps) and environmental information. Significant progress was made in both domains, with each research program involving a basic research component and a more applied usability component (as described below).

**1) Spatialized Audio displays.**

The starting point of this project was to create a cyber assistant to aid indoor spatial learning and navigation. Our first approach was to build on existing dissertation and post-doctoral work by UMaine PI Giudice by developing displays using spatialized audio. Our first two studies dealt with basic perceptual issues of psycho-acoustics by comparing user performance on orienting behavior using 2 auditory output modes, 3D virtual acoustic displays vs. external speakers. Virtual acoustic displays, in which sounds are heard as emanating from a specific distance and direction in space, can provide an intuitive nonvisual interface for presenting environmental information. These displays offer an advantage over traditional language-based interfaces because spatial information is perceived directly, rather than undergoing cognitive interpretation. The disadvantage of virtual sound is that it offers fewer auditory localization cues than are available from natural sound. The purpose of these studies was to evaluate the efficacy of virtual sound for perceiving target locations (Experiment 1), and encoding and recalling these locations from memory (Experiment 2). In both experiments, the virtual sound was compared to external speakers for finding and learning multiple target locations. Since these are critical operations for use of acoustic displays for real-time environmental access, as is the goal of our Cyber Assistant, these studies

provided important behavioral data from a simulated version of the final interface.

Our next series of studies, based on the results of the first two, looked at the best way to present environmental information through headphones (as it is impractical to use an array of external speakers in a portable context). Work during years 2 and 3 showed that virtual audio through headphones can be as effective as external speakers, but this work was based on the traditional method of sound spatialization based on tracking of head motion. However, for a cyber assistant to be readily implemented, a real-time head tracker is necessary, which is not practical for a portable navigation system.

Thus, we were interested in other modes of conveying spatialized information. This experiment employed four auditory conditions. These included a spatial

language condition, where the user is given the distance and direction of each target in a three object array, an auditory snapshot, where the stationary

user hears a spatialized recording of the distance and direction of the objects panning across the array, a head-directed exploration mode where the user's

head is tracked and objects are sounded when they are faced, and a hand-directed exploration mode where the user's hand is tracked and objects are sounded

when they are pointed to. This last condition is of particular interest, as smartphones and other portable platforms have embedded accelerometers and gyroscopes,

and as such, they can easily be tracked. Thus, if the user can accurately register their head coordinates and arm coordinates, e.g. the spatial direction

of the sound they hear from their ears to the orientation of their arm, this will prove a good solution for implementation of inexpensive portable virtual

acoustic displays.

The final set of experiments using auditory displays used a more complicated paradigm where participants needed to learn an array of objects and not only walk from a learning point to each target (as was done earlier, But also walk between targets, showing that a global representation of the targets was built up. This is similar to how a person would learn a room or indoor environment and walk between locations (e.g., an information desk, elevator, restaurant, etc). It was also implemented on an actual smartphone device, as this is the platform that will eventually be used in the cyber assistant. To further simplify the design, we used audio based on hand movements on the touchscreen, rather than tracking of the hand or head. Thus, the user searched the display and either felt, heard through spatialized audio, or from simple language where each target was. This was like having a small scale "model" of the targets that they felt / heard on the screen. They then had to walk to and between all of these targets in actual space. The importance here is that if participants can learn from searching the display (which is showing a simulated model of the room) instead of actual searching of the room, we do not need to use as many sensors and tracking to achieve the same level of learning. This would mean that implementation in a commercial device would be easier and potentially less error prone because of sensor noise.

## 2. Vibro-Audio interface design and evaluation.

The second line of research performed during this grant looked at using touch, specifically vibrotactile stimulation based on the vibration motor of a smart phone / tablet, for learning non-visual spatial information or for accessing the environment. This display could be used both before traveling to a new environment (off-line learning) and during actual travel (on-line usage), as long as the smart device was available. This display uses the existing vibration motor on a Smartphone to provide vibro-tactile cues when a user runs their finger over active regions on the touch-sensitive display. Thus, we can put a map on the display and let the user feel the map by vibrating the line when they run their finger over it. This is a new interface and an extremely significant advance in non-visual information access, as it does not involve additional hardware and would allow access to existing visual information in a direct and intuitive manner. In addition, it is based on commercially-based, inexpensive hardware, that is already owned by many potential users and can be multi-purposed, e.g., supports multiple pieces of assistive technology.

Our first studies dealt with psychophysical parameters with the display, establishing the correct vibration patterns and line width for it to be used effectively. The next iteration of this research used the parameters from the first studies in three new experiments to learn graphs, recognize patterns, and for tracing shapes. Comparisons were made between use of the vibro-audio display with traditional hardcopy tactile output, with both blind and blindfolded-sighted participants used in the experiments. The final set of studies, done in years 4 and 5, looked at use of the vibro-audio display with large format maps. Maps are challenging on portable devices as the content extends beyond the limited screen real estate. For visual displays, users simply pan and zoom the display but these operations are difficult in a non-visual context as the user loses their frame of reference with each pan or zoom action. This issue had never been studied with touch. Thus, we designed a range of different non-visual pan and zoom techniques to be used on the vibro-audio display. These were compared in a series of experiments, with a fixed view map (similar to a traditional tactile map) as the control.

Specific Objectives: This project has been extremely fruitful over the entire life of the grant. Four graduate students have worked on the project and all have successfully completed their Masters and are now gainfully employed. They have also learned a broad range of skills and training by working on this project, including technical skills such as Python, JAVA, and database design; research skills such as learning about experimental design and methodologies, data analyses and myriad statistical procedures, and writing up and presenting results. Indeed, besides their theses, we have had 17 publications and conference presentations (see products and outcomes section).

Significant Results:

The most important experimental results from grant-related work previously described are discussed below.

Findings from the research line using spatialized audio (Students Kit Cuddy and Shreyans Jain) showed:

1) Spatialized audio from headphones, using generic head-related transfer functions

(HRTFs) are as effective as externalized loudspeakers for learning and remembering target arrays. This is important as it shows that a portable assistant employing spatialized audio in headphones is a viable way to learn about the surrounding environment, which is good as this can also be implemented on a portable cyber assistant.

2. Results showed that learning about the space and receiving spatialized audio coupled to the hand was as good as the head. These results are meaningful as they corroborate the first major finding in demonstrating that a user can use a smartphone as the core of the cyber assistant and effectively use the spatialized information it provides, even though it is referenced to hand coordinates instead of the traditional head-centered coordinates. This is meaningful as it shows that devices using the advantages of spatialized audio do not need head tracking, which is expensive and impractical, but can rather simply use the existing embedded sensors in the smartphone to update the auditory cues in space.

3. Further simplifying the interface, it was shown that a user can feel the touchscreen of a smartphone and effectively learn the spatial configuration of targets in a room by moving their finger around on the display and receiving either spatialized audio or vibrotactile cues to indicate target azimuth and distance. These results suggest that there is no real need to rely on any dynamic sensors, as long as there is an underlying map, as the user can use the display on the device to learn the arrangement of objects and is actually quite good at then scaling their position to actual space in order to walk to the desired locations. Indeed, error performance with the non-visual modes was quite similar to that when using vision, supporting its efficacy for spatial learning and subsequent navigation performance. Taken together, these findings provide strong empirical support from a range of related studies for a robust spatial audio method for conveying spatial information about a building. They also show that specialized hardware is not necessary for accurate performance and that a system can be built on a commercially-available device that could be used to convey spatial information about the surrounding environment and, assuming indoor positioning were available, to give guidance information about a route between points.

The second major line of research on this project dealt with the development and evaluation of a completely new type of display, called a vibro-audio interface. This work, done by students Monoj Raja and Hari Palani, is extremely promising and represents one of the biggest advances in non-visual access in recent history. The data were clear from multiple experiments comparing this interface with traditional hardcopy tactile output.

1) We found that performance between the vibro-audio interface and hardcopy was essentially equivalent in terms of errors and reproduction accuracy when some important psychophysical parameters were accounted for. For instance, the vibrotactile line must be at least 3 times wider than the hardcopy tactile line and a duty cycle using a ratio of 75% on and 25% off, represented a good vibration pattern for optimal recognition. . This was true for both blind and sighted participants.

2) The results of our project using the vibro-audio interface for non-visual graph learning and shape recognition were definitive. Both blindfolded-sighted and blind participants were able to learn the graphs using the vibro-audio interface as well as when they learned with a hardcopy tactile map. In addition, they preferred the former interface, even though it was unfamiliar to them. Similar results were found

with time and error measures for recognizing irregular shapes and on letter identification between the 2 interface modes.

- 3) The results of the map panning and zooming studies with the vibro-audio interface were also clear. Performance with our 2-finger pan mode led to reliably better performance than the control (fixed map view) condition and our functional zoom condition led to reliably less errors than the control (fix map view) condition. Together, these studies provide support for the efficacy of our new vibro-audio interface for learning maps and give guidance for future development on the best methods to support non-visual panning and zooming operations.
- 4) Finally, the result of multiple user preference surveys suggested that people liked our new vibro-audio interface and that blind people were excited about adopting it as their primary interface for non-textual information if it were further developed. The success here with large format maps, and our new panning and zooming techniques opens the door for this interface to be used as a new tool for offline learning (i.e., learning about a space in advance of going there) or for real-time use during actual navigation (assuming indoor positioning becomes commercially available). Both applications are relevant to a fully implemented cyber assistant.

This research has significant promise for blind people and the recent interest we have received from both the assistive technology and haptic community provides important external validity that our findings, and this research program, is both timely and broadly impactful.

The combined results of the studies carried out during this project demonstrate that both virtual audio and vibro-tactile information is effective for perceiving and recalling target locations, learning simple spatial layouts, for accessing graphical material, and for map usage, including panning and zooming operations. These results provide continued support for the efficacy of using both modalities for the development of accessible spatial displays as the basis of a non-visual navigation interface that can present both environmental information and access to spatial graphics to low-vision users. Finally, As the interfaces we have studied are dynamic, they are able to be implemented on multi-use hardware, and are simple and inexpensive to implement. As such, these interfaces have huge potential applications to spatial learning and providing access to environmental information about a building, as well as graphical material like maps, which is critical for success in the classroom, workplace, or during normal daily navigation. We are very excited about extending this work to additional spatial tasks relating to navigation, especially that facilitating learning of real buildings.

Key outcomes or  
Other achievements:

**\* What opportunities for training and professional development has the project provided?**

Grant-related research during this project led to 4 masters theses, 16 conference presentations (two of which received awards of excellence), and one journal publication. Several more journal papers based on the theses are currently being written up for publication.

Relevant courses taken by students during this project relating to grant-related research included: Human-computer interaction (SIE 515), virtual reality and research (SIE 516), and research methods (SIE 503).

The skills and training they learned while working on this project have served all of our students well. Mr. Raja accepted a job at ESRI, the leading company in spatial analysis and mapping, Mr. Jain accepted a job at Gallup Inc. doing spatial research, MS. Cuddy accepted a research position at the prestigious Jackson labs, and Mr. Palani was accepted into the Ph.D. program at UMaine to continue his studies working under my supervision.

### \* How have the results been disseminated to communities of interest?

As described elsewhere in this report, we have also presented the work as part of sixteen conference submissions and as a cover story in UMaine Today with a 90,000 readership.

## Products

### Books

### Book Chapters

### Conference Papers and Presentations

Jain, S. & Giudice, N.A. (2011). *Assessing Audio Interfaces for use in an Indoor Navigation System*. Conference on Spatial Information Theory. Belfast, ME. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Jain, S. & Giudice, N.A. (2012). *Assessment of spatial audio interfaces for blind and low vision users*. Think Tank Consortium, in conjunction with the International Conference on Auditory Displays. Atlanta, Georgia. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Palani, H. & Giudice, N.A. (2013). *Assistive Technology for Visually-Impaired persons..* UMaine Graduate Expo. University of Maine-Orono. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Jain, S. & Giudice, N.A. (2012). *Comparing head versus hand motion based spatial audio interfaces for indoor navigation*. UMaine Graduate Expo. University of Maine-Orono. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Raja M.K. & Giudice N.A. (2011). *Haptic Spatial Learning of Indoor Spaces using Touchscreen enabled Smartphone devices..* Conference on Spatial Information Theory. Belfast, ME. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Cuddy, K.M. & Giudice, N.A. (2009). *Information Requirements for Indoor Navigation..* UMaine Graduate Expo. University of Maine-Orono. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Giudice, N.A., Palani, H., Brenner, E., & Kramer, K.M., (2012). *Learning non-visual graphical information using a touch-based vibro-audio interface..* Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility. Boulder, Colorado. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Giudice, N.A. (2012). *Moving beyond the vision-only bottleneck: Using multimodal information in virtual reality research. When is virtual reality real enough?.* Workshop on Using VR in spatial Cognition research. In conjunction with Spatial Cognition 2012,. Kloster Seeon, Germany. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Giudice, N.A. (2009). *Multimodal Processing of Spatial Information: The Intersection of Spatial Cognition and Neurocognitive Engineering*. Institute for Research in Cognitive Science. University of Pennsylvania. Status = OTHER; Acknowledgement of Federal Support = Yes

Jain, S. & Giudice, N.A. (2012). *Navigating Indoor Spaces with Spatial Audio..* Association of American Geographers annual meeting. New York. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Palani, H. & Giudice, N.A. (2012). *Navigation assistance for visually impaired persons using touch based devices*. UMaine Graduate Expo. University of Maine-Orono. Status = PUBLISHED; Acknowledgement of Federal Support =



Yes

Cuddy, K.M. & Giudice, N.A. (2010). *Spatialized audio for remembering auditory target azimuths*. Spatial Cognition 2010 Conference.. Ft. Hood, Oregon. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Giudice, N.A. (2013). *The role of touchscreen displays for non-visual graphical access*. Tactile Research Group Annual Meeting. Toronto, Canada. Status = OTHER; Acknowledgement of Federal Support = Yes

Giudice, N.A. (2011). *Toward universal access to seamless travel of indoor and outdoor spaces with and without vision*. Center for Transportation Studies. University of Minnesota, MPLS, MN. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Giudice, N.A. (2012). *Using multimodal information displays in spatial cognition research*. University of Hamburg. Hamburg, Germany. Status = OTHER; Acknowledgement of Federal Support = Yes

Giudice, N.A. (2013). *Workshop on Environmental Sensing Technologies for Visual Impairment (ESTVI 2013)*. ESTVI 2013. Smith-Kettlewell Eye Research Institute, San Franc. Status = OTHER; Acknowledgement of Federal Support = Yes

### **Inventions**

Nothing to report.

### **Journals**

Klatzky, R.L., Giudice, N.A., Bennett, C.R., & Loomis, J.M. (). The promise of touch-screen technology for the dynamic display of 2D spatial information without vision. *Multisensory Research*. . Status = AWAITING\_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

### **Licenses**

Nothing to report.

### **Other Products**

Nothing to report.

### **Other Publications**

### **Patents**

Nothing to report.

### **Technologies or Techniques**

Nothing to report.

### **Thesis/Dissertations**

Jain, S.. *Assessment of Audio Interfaces for Use in Smartphone Based Spatial Learning Systems for the Blind*. (2012). University of Maine. Acknowledgement of Federal Support = Yes

Palani, Hari.. *Making Graphical Information Accessible Without Vision Using Touch-Based Devices*. (2013). University of Maine. Acknowledgement of Federal Support = Yes

Cuddy, K.M.. *The Efficacy of Virtual Spatialized Audio for Perceiving and Remembering Azimuths of Auditory Targets*. (2010). University of Maine. Acknowledgement of Federal Support = Yes

Raja, M.K.. *The development and validation of a new smartphone based non-visual spatial interface for learning indoor layouts*. (2011). University of Maine. Acknowledgement of Federal Support = Yes

### **Websites**

VEMI Lab

<http://www.vemilab.org/>

Work has been discussed and disseminated on this website.

## Participants/Organizations

### What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Giudice, Nicholas	PD/PI	12
Cuddy, Kate	Graduate Student (research assistant)	12
Jain, Shreyans	Graduate Student (research assistant)	12
Palani, Hari	Graduate Student (research assistant)	12
Raja, Monoj	Graduate Student (research assistant)	12
McGrath, Tim	Undergraduate Student	12

### Full details of individuals who have worked on the project:

#### Nicholas Giudice

**Email:** nicholas.giudice@maine.edu

**Most Senior Project Role:** PD/PI

**Nearest Person Month Worked:** 12

**Contribution to the Project:** PD/PI

**Funding Support:** None

**International Collaboration:** No

**International Travel:** Yes, Canada - 0 years, 0 months, 4 days; Germany - 0 years, 0 months, 3 days; Germany - 0 years, 0 months, 5 days

#### Kate Cuddy

**Email:** kate.cuddy@maine.edu

**Most Senior Project Role:** Graduate Student (research assistant)

**Nearest Person Month Worked:** 12

**Contribution to the Project:** Helped in design, preparation and conducting grant-related research that will be part of her Masters thesis work.

**Funding Support:** None

**International Collaboration:** No

**International Travel:** No

#### Shreyans Jain

**Email:** shreyans.jain@maine.edu

**Most Senior Project Role:** Graduate Student (research assistant)

**Nearest Person Month Worked:** 12

**Contribution to the Project:** Grad student helping to design and conduct grant-related research.

**Funding Support:** None

**International Collaboration:** No

**International Travel:** No

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**Hari Palani**

**Email:** Hari\_Palani@umit.maine.edu

**Most Senior Project Role:** Graduate Student (research assistant)

**Nearest Person Month Worked:** 12

**Contribution to the Project:** Grad student running grant-related experiments

**Funding Support:** None

**International Collaboration:** No

**International Travel:** No

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**Monoj Raja**

**Email:** monojkumar2001@gmail.com

**Most Senior Project Role:** Graduate Student (research assistant)

**Nearest Person Month Worked:** 12

**Contribution to the Project:** Grad student helping to design and conduct grant-related research.

**Funding Support:** None

**International Collaboration:** No

**International Travel:** No

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**Tim McGrath**

**Email:** Timothy\_McGrath@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 12

**Contribution to the Project:** Programmer, helped with experiments

**Funding Support:** None

**International Collaboration:** No

**International Travel:** No

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**What other organizations have been involved as partners?**

Nothing to report.

**What other collaborators or contacts have been involved?**

NO

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## Impacts

### **What is the impact on the development of the principal discipline(s) of the project?**

The research conducted during this project provides a basic foundation for the efficacy of the use of both 3D virtual acoustic displays and vibro-audio displays for providing non-visual spatial information for use in both offline and real-time spatial learning and navigation systems. Although previous work with auditory displays has suggested that they are beneficial, the main contribution of the current work is to show that we can implement these displays on a portable device (e.g., a smartphone) and use hand tracking, rather than the tradition head tracking, to deliver the information. These are the first studies to directly compare these tracking modes for spatialized audio and the results important, as current technology is already embedded in smartphones to perform the necessary tracking, whereas this would not be possible if head tracking was found to be required (as it would necessitate the addition of expensive external hardware). In addition, our newly developed vibro-audio interface will be of interest to haptic researchers and interface design engineers, as it allows provision of important spatial information using existing hardware—thereby creating a low-cost but highly functional new accessible user interface. This is a highly innovative solution to an old problem (i.e. using touch to provide access to graphical material), and promises to have broader impacts to both assistive technology and eyes-free applications (e.g., driving.)

### **What is the impact on other disciplines?**

The scope of this project is inherently interdisciplinary, as the PIs from the four collaborating institutions have expertise in widely varying domains. For instance, the work I am carrying out at UMaine has obvious application to blind spatial cognition and Psychophysics of spatial hearing, as well as relation to the development of audio and vibro-tactile interfaces and HCI design, which has relevance to colleagues in Computer Science, human factors engineering and other engineering disciplines dealing with audio or vibro-tactile information processing or interface design.

### **What is the impact on the development of human resources?**

Although the current scope of the project is not directly addressing human resource issues, the results suggest that both virtual audio and vibro-tactile feedback are effective methods for conveying spatial information through different non-visual mediums. This has obvious application for conveying information which is traditionally in a visual format through an accessible means. We are interested in usage for specifying environmental information but such displays could be used for learning and teaching many visual concepts, such as geography, biology, chemistry, or data visualization.

### **What is the impact on physical resources that form infrastructure?**

Nothing to report.

### **What is the impact on institutional resources that form infrastructure?**

Nothing to report.

### **What is the impact on information resources that form infrastructure?**

Nothing to report.

### **What is the impact on technology transfer?**

The development of our vibro-audio interface has broad-based applications to assistive technology and commercialized free applications (e.g. interfaces for use in cars and/or planes). We believe that with further development this technology has a high probability of transferring to the commercial market.

### **What is the impact on society beyond science and technology?**

As discussed in the prior section, our findings have significant import to the use of 3D audio displays and vibro-tactile interfaces for conveying non-visual access to spatial information. There are many instances where such displays could aid the teachig of spatial concepts and help in the development of a mental model of material which is generally accessed through visual apprehension.

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## Changes/Problems

### **Changes in approach and reason for change**

Nothing to report.

### **Actual or Anticipated problems or delays and actions or plans to resolve them**

Nothing to report.

### **Changes that have a significant impact on expenditures**

Nothing to report.

### **Significant changes in use or care of human subjects**

Nothing to report.

### **Significant changes in use or care of vertebrate animals**

Nothing to report.

### **Significant changes in use or care of biohazards**

Nothing to report.