HaptiGo Tactile Navigation System

Kate Boxer,Essa Haddad, Sarin Regmi, Alex Reynolds
Sketch Recognition Lab
Texas A&M University

ABSTRACT

Tactile navigation systems employ the use of ones sense of touch with haptic feedback to communicate directions. This type of navigation presents a potentially faster and more accurate mode of navigation than preexisting visual or auditory forms. We developed a navigational system, HaptiGo, which uses a tactile harness controlled by an Android application to communicate directions. The use of a smartphone to provide GPS and compass information allows for a more compact and user-friendly system. HaptiGo has been tested for functionality and to determine general receptiveness to haptic navigation. It was further tested to determine if tactile navigation provides for shorter navigation times, more travel accuracy than traditional visual navigation methods, and improved environmental awareness. We discuss the novel usage of smartphones for tactile navigation, the effectiveness of the HaptiGo navigation system, its accuracy compared to the use of static map-based navigation, and the potential benefits of tactile navigation.

Author Keywords

Haptics, tactile navigation, Android, mobile phones, smartphones, handheld displays, Arduino, Amarino, Bluetooth, GPS, wearable computing fabrics, Google Maps

INTRODUCTION

Introduction to Navigation

Maps have long been recognized as the key to navigation. Often coupled with a spoken or written list of directions or additional information about the route, it is to maps that people turn when seeking to guide themselves through foreign territories. In modern times, we have the option of both paper and dynamic electronic maps, found on devices such as smartphones, GPS devices (both handheld and those integrated into automobiles), tablets, etc. As before, these navigation systems are frequently coupled with auditory instructions as well as an option for textual listed directions. Despite the advancement of these systems to provide users with easy and understandable navigational instruction, visual and auditory navigation may not be the most effective modes of navigation. Visual navigation methods, such as maps and GPS displays, require time for the user to orient themselves to the map and interpret it in relation to their surroundings. When referencing a map, either dynamic or static, a user must take the time to decipher the map, and then take the information they have gathered and use it to determine their location and direction in relation to their actual environment. Auditory instruction requires much of the same; users must spend time searching the area for landmarks to orient themselves prior to and throughout navigation. Tactile navigation requires no orientation time or understanding of environment on the users part. We believe tactile navigation to present a more accurate method of navigation than those described above.

Different Forms of Navigation

Tactile navigation is a less intrusive form of navigation than that of visual and auditory navigation. Other navigation systems require the user to direct their attention towards a visual aid such as a map, or auditory instructions, such as an audio recording accompanying a GPS. Having to focus on a map may distract a user from their surroundings. A backlit GPS device may be intrusive to others in a dark environment. Auditory instruction can interrupt conversation or music. Tactile feedback also allows for instantaneous communication of instruction. Instead of having to wait several seconds for an instruction to be vocalized or to orient oneself to a direction on a map, an actuator will vibrate, giving the same instruction in a fraction of the time. The constant directional feedback combined with minimized mental processing yields faster and more accurate navigation. Tactile feedback also has potential for those with disabilities. The blind, in particular, would benefit greatly from the advancement of accessible haptic technologies. Tactile navigation would allow the blind a more subtle and more efficient means of navigation other than the use of seeing-eye animals, and could be more finely tuned to their needs than that of an animal. Wearable haptics would also be a communication method less susceptible to interference; a service animal may be distracted by external impulses, auditory instruction may be lost amongst the noise of the environment. Haptic signals, on the other hand, are transmitted directly to the body, and cannot be intercepted or lost through external means.

Accessibility

The use of a smartphone to provide the necessary information for this technology greatly increases the overall accessibility of the product. Smartphones are rapidly becoming the norm in modern society. If desired, one could install the necessary Android application and have it running on their phone in mere seconds. Coupled with the tactile hardwares ability to be integrated into easily worn and unobtrusive clothing, such as a light harness or a shirt, HaptiGo is a project that could be made easily accessible to the average person at no great inconvenience.

The minimalistic approach to HaptiGos construction also greatly reduces the cost of production for the harness. While earlier tactile navigation systems employed at least six actuators, with the more successful systems using six to eight, HaptiGo only uses three, detracting from the expense needed to reproduce such a system. All of the components of the harness are also affordable, the most expensive part being the LilyPad at $20. Such affordability could make tactile navigation a navigation method easily accessible to the masses.

RELATED WORK

Previous Works

Research in visual- and audio-based interaction systems has been conducted throughout the past two decades, while current research has shifted to the use of tactile feedback as a more intuitive, more unobtrusive, and less mentally demanding means of interaction. This research has focused more on military applications [1,8,16] and navigation systems [17,18,15,12,2,5].Studies have also been conducted wherein different modes of interactions (visual, audio and tactile) are combined to provide contextual information of the physical world(paper 8,9). Additional studies have integrated augmented reality with tactile, audio and visual aids to create an information rich system[3,4,5,9,7].

[9] discussed the benefits of tactile feedback in situations where audio and visual cue channels are overloaded. [Paper 8] expands on these benefits and proposes the use of tactile alerts to provide situational awareness to platoon leaders during high workload military operations. This implementation is further supported by tactile displays used as communication systems for pilots and astronauts, providing directional cues to aid spatial orientation [10,11,14], as well as being used to aid navigation [1,2,3,5,17].

[4] describes a head-mounted tour system designed for Columbia University. It is based on augmented reality and depends on different visual cues and interaction forms. Paper 3 extends this idea with a more general form of hands free wearable navigation system. Such systems have not been streamlined for general use given the expensive, bulky and ungainly hardware they use.

[2,5,18] present a tactile-based fully functional navigation system where a belt is used to provide haptic feedback to users. Van Erp et al. [18] showed that pedestrians are able to follow a route consisting of waypoints guided only by a tactile belt. However, the limited number of displayable directions caused the users to travel along indirect routes between waypoints in some cases. GentleGuide [12] proposed an indoor tactile navigation system via two bracelets. It outputs three commands: left, right, and stop (both bracelets activated). Tactual Wearable Display [13] attached a matrix of vibrators to the back of a vest, and tried to transmit directions and other information to user. [16], with the use of a tactile vest, presented a scenario where it was hard to conclude whether tactile displays made significant effect on situational awareness. It did conclude, however, that the addition of tactile displays to other systems can improve the performance rather than being used exclusively. [15] extends the work of [2] to design a solely tactile based navigation belt with more precision in directing users.

Relation to HaptiGo

The use of the vibration actuators on the shoulder can be argued to be the most effective method of delivering directions via vibrations. In the [2], the vibrations are delivered through a belt to the lower torso. This region of the body is less sensitive than the shoulders and upper back, as used in HaptiGo. The actual usability of the Activebelt is questionable, due to the fact that the vibrators must be adjusted on the belt according to waist size. Our haptic harness can easily be worn over most clothing. In addition, the adjustable straps allow it to be fit to users of all shapes and sizes. In the [16] a tactile vest structurally similar to ours is described. However, this vest is significantly more constraining than the harness we designed. Our vest has an open front, and uses a minimal amount of material, providing for unrestricted movement and increased comfort. Projects such as [3, 4, 5, 7, 9] use excessive external hardware to receive GPS signal, compass bearing, and other pieces information. [4] requires a backpack full of equipment, and [3] that requires augmented reality goggles as well as a backpack. HaptiGo, on the other hand, requires only a small vest and a smartphone. Smartphone usage is on the rise; it is predicted that 1 in 2 Americans will own a smartphone by the end of 2011. This, combined with the compact size of the phones makes HaptiGo one of the most accessible versions of tactile navigation.

IMPLEMENTATION

Implementation os HaptiGo

The users objective is to navigate along a course from a starting point to a final destination. The navigation path is broken into segments using waypoints. The course segments are straight paths, and the waypoints are located at the vertices of the segments. The process of navigation consists of navigation to a waypoint until the user is within a set radius of the point, upon which the cycle repeats until there are no waypoints remaining. HaptiGo and the Arduino Lilypad code work together to receive GPS signal, bearing, and deliver a constant stream of vibrations to user to direct them through waypoints to a final destination.

Hardware

The central control unit of the HaptiGo harness is a LilyPad Arduino ATmega328V microcontroller (2). The circuit is powered by a 3.7V cell phone battery (4). Conductive threads (1) connect the LilyPad control board ports to three Arduino LilyPad Vibe Boards, the actuators used to send haptic signals to the wearer. Signal communications between the Android smartphone and the LilyPad control board are conducted via a BlueSMiRF Silver Bluetooth modem (3). A variety of Android smartphone models were utilized throughout the development. The most frequently used phone was a Motorola Atrix 4G, equipped with a sim card/data plan, running the Android 2.2.2 platform. Motorola Milestones were also used, running the Android 2.2.1 platform. These phones were not equipped with sim cards/data plans. The internal GPSs of the phones were accessed for GPS information, as well as to provide compass information.

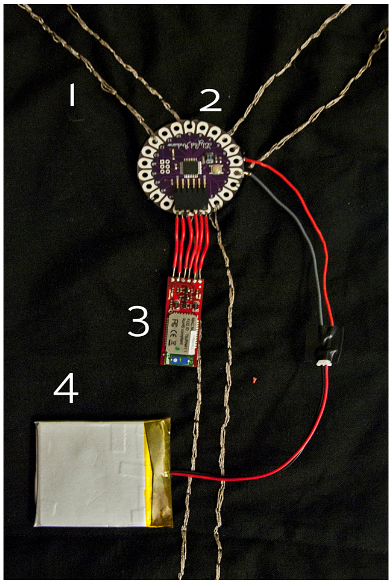


Figure 1. Hardware

Arduino Software

The Amarino toolkit was used to provide a connection between the Android phone and the Arduino LilyPad via Bluetooth, so we could send and receive data between the two. The Arduino methods are responsible for activating and deactivating the LilyPad actuators. The frequencies of the vibrations are based on data calculated by and sent from the HaptiGo application.

Navigation with HaptiGo

HaptiGos navigation waypoints are obtained from Google Maps or Google Earth manually and processed into location objects. A location object consists of longitude and latitude information, and provides methods that are useful for calculating bearings, distances and speed. These location objects are loaded into a queue, and the program then leads the user to each waypoint in the order that they appear on the path.

There are two kinds of information obtained from the phone that are essential to HaptiGos function. First is the users current location, which is updated frequently. In the Android application, a Location Listener, registered to a Location Manager object, was used to acquire constant location updates by using the Android GPS. Second is the compass bearing, which is measured in degrees east of true north. We used the internal Android compass, and created a receiver that constantly updates the bearing.

To keep a constant stream of haptic signals, a timer is called in the Android application. This timer sends a signal to an Arduino code every three seconds. Once Arduino receives this signal, it returns a piece of data to the Android application, triggering an ArduinoReceiver in the Android code. In the ArduinoReceiver, methods are then called to calculate and instruct the Arduinos vibrational patterns.

The majority of the activity is called from within the ArduinoReceiver. When first called, it checks to see if the current location of the user is within a five meter radius of the next waypoint (radius is increased for driving tours). If the current location is within the radius the program registers that the user has reached the waypoint, notifies the user that theyve reached a point, and accesses the next waypoint in the locations queue. If the user is not within the waypoint radius, the program sends vibrations to the user to navigate the user to the next waypoint.

The program determines the haptic signals by calling a method that determines if the user needs to veer right, left, or continue straight to access the next waypoint. This is determined by a turning algorithm which determines whether a right or left turn is more efficient in a given situation, as well as calculating the necessary turning angle.

The algorithm uses two values: the users current bearing (in degrees east of true north) and the bearing to the next destination. The bearing to the next destination is calculated by a method in the Android library, and is based upon the users current position and the desired location; the method determines the path of shortest distance to the desired location, and returns the bearing of that path of travel (again in degrees east of true north). The turn algorithm is as follows:

- If the bearing to the next destination is greater than the current bearing, check to see if the current bearing + 180 degrees is still less than the bearing to the next destination. That is, if a 180 degrees turn to the right will still not bring the user to or beyond the desired bearing. If this is so, it is more efficient to turn left. If not, a right turn is more efficient.
- Else, if the current bearing minus 180 degrees (a 180 degrees turn in the left direction) still does not bring the user to the desired bearing, turn right.
- Otherwise, the user is instructed to turn left. This case is simply a catch-all case, and is only relevant when the necessary turn angle is 180 degrees; in such a situation, both right and left turns are equally efficient.

The necessary turning angle also determines the duration of a specific vibration. The larger the angle, the longer the duration of the vibration sent to the user. Once the direction of the user, and the frequency of the vibration is calculated, it is sent to the Arduino Lilypad, which then responds with the appropriate vibrations. This is the process takes place every three seconds based on the timer.

GPS Limitations

Table 1.

Turning Angle(in degrees)	Vibration duration
less than 20	straight,250 milliseconds
20-30	left/right,200 milliseconds
30-60	left/right,350 milliseconds
60-90	left/right,500 milliseconds
90-135	left/right,750 milliseconds
135-180	left/right,1 second

HaptiGo encountered the standard GPS issues that all GPS-based applications face. If the user is in between tall buildings, or close to a building with a lot of glass in the structure, the GPS will not send accurate information. The application will not receive any sort of signal inside buildings, and thus cannot function indoors. Since our application is mostly used for walking, and deals with smaller distances between waypoints it is extremely important for the current location information to be accurate. This limited us to only designing courses that were in open spaces. Although this was a limitation to our version of the navigation system, as GPS technology improves, the system will be able to utilized in a greater variety of areas.

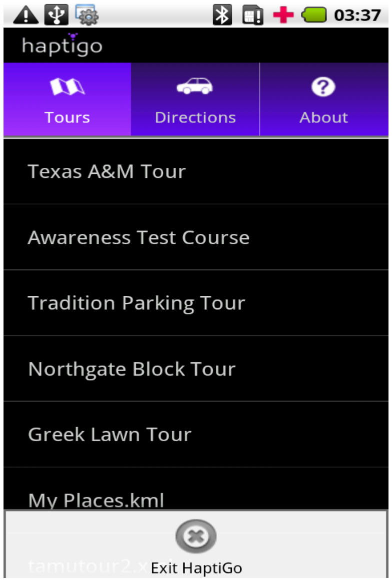


Figure 2. Tour Listing

User Interface and GeoPoint Retrieval

Our Android application, HaptiGo, is capable of performing the following tasks:

- Retrieve route coordinates, landmark coordinates, and their descriptions from a set of tours that come with the application, as well as from a special Maps folder created by the application on the SD card where users can load their own cutomized KML files that can be created on Google Earth.

- Draw a route path, along which all landmarks are identified and marked with interactive pins. When selected, a dialog box appears, which displays information about the selected location.

- Play informative audio files when a landmark is reached.

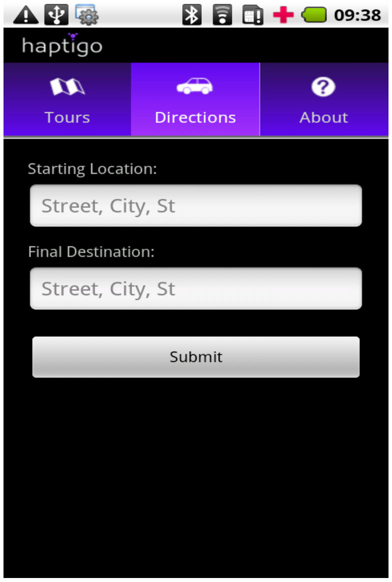


Figure 3. Driving Directions

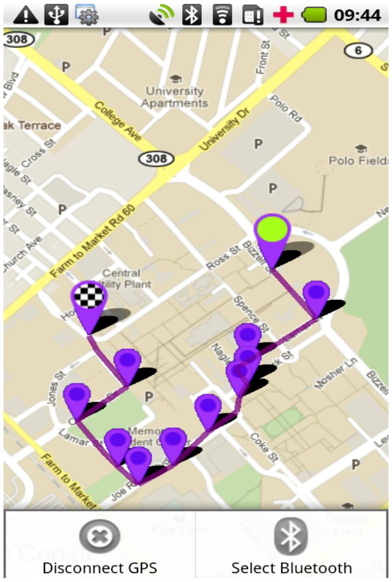


Figure 4. Texas A&M Tour

HaptiGo processes KML files generated by either Google Earth, for customized tours loaded from the SD card, or Google Maps for customized driving directions. The KML files have a unique XML tag structure that makes it easy for developers to identify the most important elements in the file and parse them. HaptiGo utilizes a SAX parser with a Default Handler in order to parse the KML file and retrieve route coordinates, headings, and landmarks names and descriptions.

HaptiGo focuses on retrieving the landmark names and descriptions for the walking tour files only. Driving directions using Google Maps will only provide landmarks that represent major turning points in the planned route.

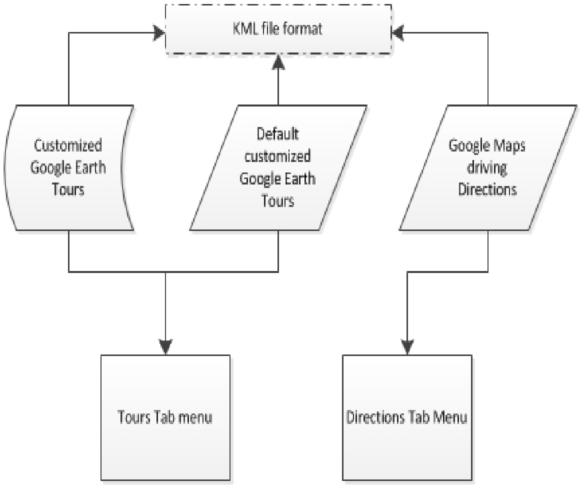


Figure 5.

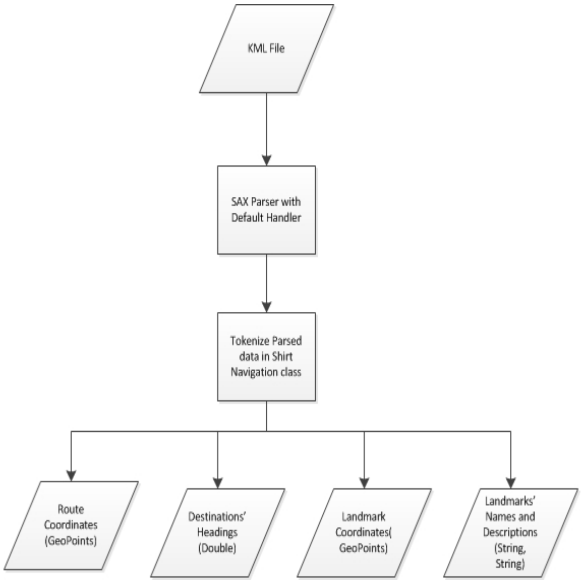
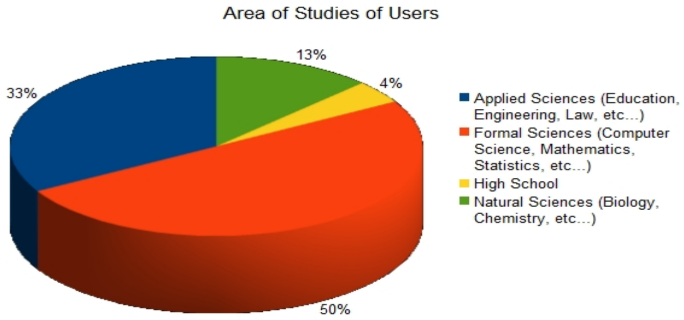


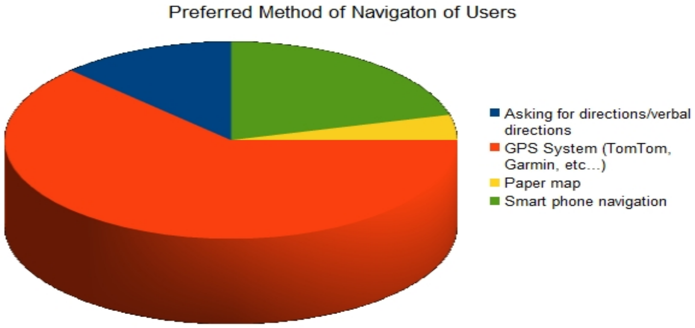
Figure 6.

USER TESTING

Participant Pool

In total, we performed total number ever recorded user tests with HaptiGo. Information about the participants, as well as their reactions to HaptiGo, were gathered via online survey. All of the test participants were between the ages of 16 and 30. The majority of the users have completed a high school education. The vast majority of the participants had never heard of haptics before. Those that had were all studying in the Computer Science and Engineering field. Of all of our users, 58.4 % owned smartphones.





Testing Setup

The courses were set on the top level of a parking garage, an area that provided an empty for the users to walk in, as well as an open space free of sky obstructions, so we could receive the best GPS signal possible. The GPS was consistently accurate to 2-4 meters in this location. For all of the functionality tests, a Motorola Atrix 4G (equipped with data plan) was used. The data plan ensured better GPS connectivity and accuracy. Aside from HaptiGo, Googles application My Tracks was used. My Tracks allowed us to document the exact path that the user traveled during the course of the testing, as well as information such as their average speed, time spent traveling, distance traveled, etc. One of the test proctors would follow slightly behind the participant as they proceeded through the course, to keep an eye on the Bluetooth connection (an LED on the Bluetooth modem indicated if it was connected or not) and to ensure that the actuators were still vibrating as planned at regular intervals.

Functionality Testing

- **Evaluation**

  The purpose of the functionality experiment was to receive user feedback about our haptic harness navigation system, as well as test general responsiveness to tactile navigation. We began testing while the system was still in its developing stages. We continued to make modifications and fix errors while testing, which yielded more favorable results and reactions over time.

  For the functionality tests, a secondary testing application was used on the smartphone. The application was very basic, the GUI consisting of only three buttons: one to initiate the walking tour, one to sever connections with the

Bluetooth modem, and one to exit the application. The application ran the users through a set of hard-coded points (points initialized within the application, rather than from an external XML or KML file), and served merely as a method to test the actual harness, rather than the full project. The plotted course was short, approximately 300 feet long, and navigated the user through four waypoints at scattered locations.

Prior to the testing process, the test participants were briefed on the purposes of the haptics project and some basics about the construction of the harness. We explained that the harness was going to use vibrations to navigate them through a course comprised of a series of points. They were told that there were three tactile actuators built into the harness, but we did not explain to them how to interpret the signals, to allow for unbiased interpretation. The participants were then fitted into the harness by the test proctors, with the straps being adjusted to fit the harness as snugly as possible, so all of the haptic signals could be clearly felt. They were told to hold the smartphone flat out in front of them, about level with their navel, then instructed to simply walk wherever they thought the harness was telling them to walk.

The test was ended once the user either reached the final destination point, or when the Bluetooth disconnected.

- **Results**

  Many of the users were initially startled when the actuators began buzzing, regardless of being alerted to their function prior to the test. However, all of the participants became accustomed to the vibrations within a very short period of time, and none of them reported finding them uncomfortable. Several of the users commented that they occasionally found the vibrations irritating; however, their comments were directed more at the implemented vibrational pattern. They found the frequency with which the actuators went off to be too high; we decreased the frequency to once every three seconds, and received no further complaints.

  We noticed that many of the participants reacted to the vibration signals with very sudden, sharp turns. They would zig-zag through the course, wasting time traveling back and forth over the designated path rather than continuously progressing forward. After observing this behavior in several successive tests, we began to instruct the participants to veer in the direction that they were being told to go–that is, to continue traveling forward while bearing slightly to the right/left. This instruction kept the participants constantly moving forward, and for the most part put a stop to the zig-zagging behavior.

  An intriguing observation was that many of the users would look at the smartphone for visual indicators, regardless of their being told that there was nothing of use to them on the display. This supports the idea that people are more inclined toward visual navigation techniques at the moment. We believe that with time and continued exposure to haptic navigation, people could become equally accustomed to this form of navigation. Alternatively, tactile navigation could be integrated into the navigation systems that people are already predisposed towards.

  Users rated the efficiency of the navigation system to be a 6.6 out of 10, 10 being most efficient. Users gave the vibrational patterns a 5.7 out of 10 for clarity, 10 being very easy to understand.

	Fairly Easy	Neutral	Difficult
How easy or difficult was the task of navigating with the haptic harness?	54%	38%	8%

	All the Time	Sometimes	Not at All
Did you notice any kind of vibrational patterns indicating how much you should be turning?	13%	69%	19%
Did you find the vibrationot ns irritating?	0%	6%	94%

- **Discussion**

  Users stated that they wished that were given instruction to veer rather than make sharp turns. They also complained that the straight actuator was placed in such a way that it was difficult to feel. However, this issue was addressed in the next version of the harness. Aside from that, users felt that the system was self-explanatory.

  The original prototype of the system only sent haptic signals whenever the GPS location was updated. Problems arose when the user stopped moving, or traveled in tight circles, a common occurrence when the signals were unclear. We went on to implement a timer so that the signals were not based on GPS updates.

  After heavy use of the hardware, parts of the hardware lost functionality, namely the Bluetooth modem. Before we found a new way to connect the bluetooth to the Arduino Lilypad, there were a lot of uncompleted user tested. This means that most users were unable to complete the entire courses lead out for them because of failure of the Bluetooth. Most of these users did at least half of the course, and were able to still give feedback.

Efficiency Testing

- **Evaluation**

  We hypothesized that tactile navigation via HaptiGo would yield faster navigation times and more accurate navigation paths than navigation through a course via paper map. Though modern dynamic maps, such as those found on smartphones and GPS systems, eliminate the need for map

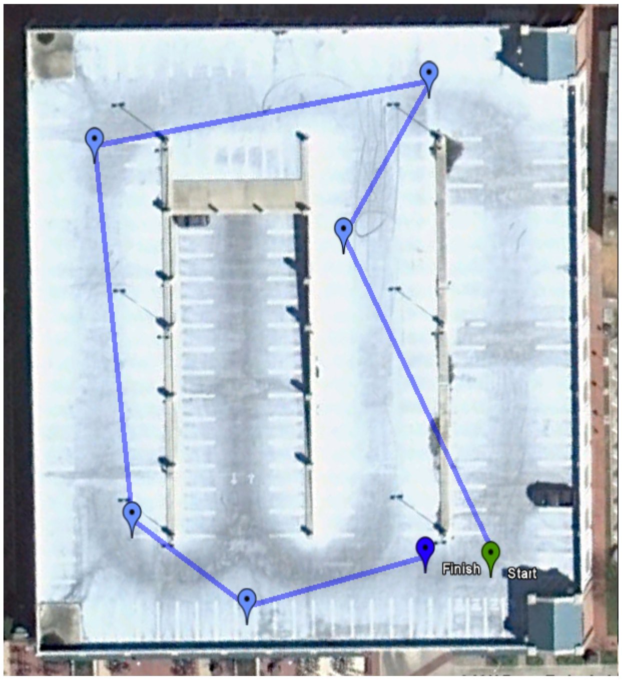


Figure 7. Course A

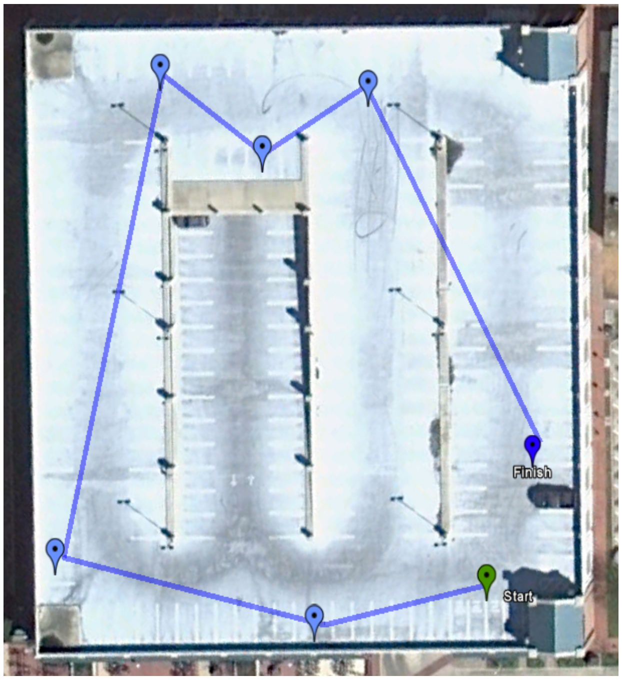


Figure 8. Course B

orientation, they often still necessitate landmark recognition and an initial moment for orientation to ones surroundings. Tactile navigation directs the user along the line of shortest distance to the points along their path, requiring only an understanding of the signalling patterns.

All users were run through a 200-foot test course consisting of four points, in order to give them time to become accustomed to our tactile navigation system. Those with prior experience were run through the training course once, to refresh their memory. Those with no previous experience went through the training course twice. All users were allowed to ask questions about the navigation system, such as the meaning of the signals, how best to go about turning, and so on. It was at this point in the testing that it was explained that one should veer rather than perform a sharp turn when signalled. It was also here that most users noticed and questioned the vibrations signifying that one has reached a waypoint or a destination.

Once the test participant was comfortable with the navigation system, and the test proctors assured that they had at least a basic understanding of the workings of the system, they were walked from the training course area to the starting area of two preset test courses, course A and course B. Both courses consisted of 7 waypoints, and were 650 feet in length, spanning the entire area of the garage level. The waypoints of each course were marked with a chalk circle containing the course letter and the number of the waypoint (i.e. the points of course A were labelled A1-A7). The user was told that there were two test courses, one of which would be navigated by traditional visual methods, one via tactile navigation. They were alerted to the fact that they would be timed, though it was stressed that they need not rush through the course, merely travel at a comfortable pace.

A coin toss was used to determine if the user was to go through the first course using tactile navigation or a paper map. The same method was used to decide which course the user was to take, A or B.

When proceeding through the map course, the participants used a paper printout of the course (cite image). They were instructed to look for the circular markings as a verification that they had reached the waypoints, and told that once they could see the marking and verify that it was the correct point, they were allowed to proceed on to the next point. This allowance simulates the 5 meter waypoint radius allowed by the haptic harness; the markings were not distinguishable from a distance of farther than a few meters. The users were not given the actual map until the timer was started.

When proceeding through the haptics course, they were not told to look at the markings on the ground. They were there to be referenced if necessary, but as there were two sets of course points marked on the ground, the users knew that navigating toward any kind of marking was unhelpful, as it was impossible to distinguish which course they belonged to until one was closer to the point.

If the Bluetooth modem disconnected for any reason during the haptic navigation course, the timer was paused, to give time to reestablish the Bluetooth connection. Once the connection was secure, the timer would be turned back on, and navigation could continue.

Upon successful completion of both courses, My Tracks was turned off, the users times for each course were documented, and the users were again emailed a survey asking about their opinions of HaptiGo and commentary on the process and how it could be improved.

- **Results**

  When users were told that they to be timed, they walked at a faster-than-average pace, and some began disregarding the signals in an attempt to complete the course as quickly as possible. After realizing that our some user had missed waypoints, we had to start them from the beginning of the course. The farther they traveled away from a waypoint, the more confusing the navigational signals became, and oftentimes the test would have to be restarted. However, this issue did not arise when users traveled at a more average walking pace.

  When using the map, we found that the users had trouble orienting themselves. At the beginning of the test, users would often misread the map and walk in the opposite direction of the course. Many missed waypoints, and had to backtrack through parts of the course. Much time was wasted circling an area, searching for the actual waypoints. Users also spent a lot of time simply stopping and staring at the map to plot out their route, a halting behavior not seen during tactile navigation.

  Although haptics did not prove to be more time-efficient than traditional map navigation, it lead users along a more accurate path, in terms of total distance traveled versus course length. When using a t-test to compare the distances of the haptic and map navigation paths, we are [] confidence that there is a significant different of between the two type of navigation, with a p-value of [] and degrees of freedom of .

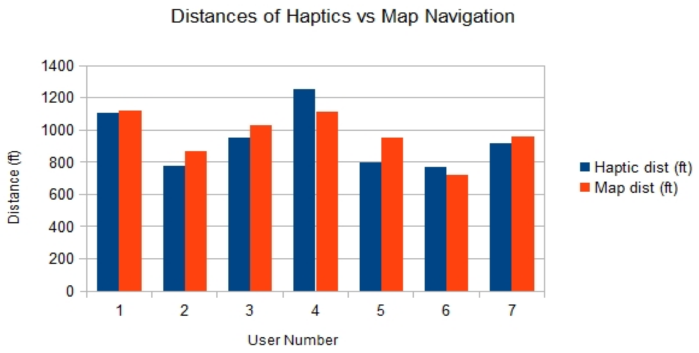
	Haptics	Map
Mean Distance(ft)	940	966
Mean Time(sec)	248	225

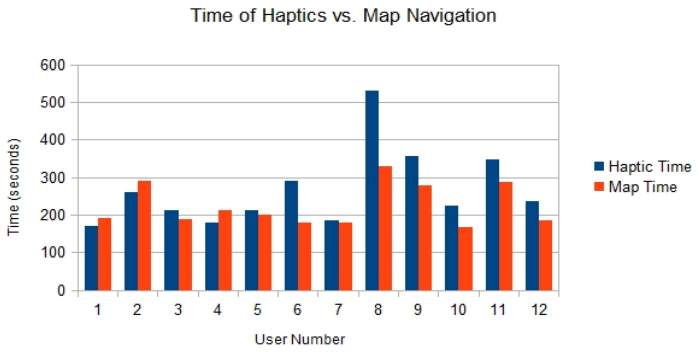
- **Discussion**

  HaptiGo is a more accurate form of navigation than the traditional visual navigation. Haptigo provides a constant stream of instructions via vibration to users. In addition, it responds to every turn and movement that the user makes. Unlike traditional maps, HaptiGo immediately corrects a user when veering off of the course.

  Like all new technology, users need to get used to vibration frequencies, turning methods, and so on. Although the data did not show HaptiGo to be more time efficent in our user tests, we believe that with the right user training HaptiGo could be just as time efficient as traditional navigation.

  HaptiGo makes use of the Android smartphones internal compass, and thus necessitates holding the smartphone like a compass. During the navigation process, the phone must be held directly in front of the user, pointing in the same directing as the user is facing, to receive correct compass/bearing information.





  The addition of an external compass would eliminate this need. We attempted to integrate a Honeywell HMC6352 compass module to provide bearing information, but we had difficulties in acquiring consistently accurate readings. A tilt in the module would yield inaccurate readings, a problem difficult to overcome when the compass is attached to a soft harness that is constantly being adjusted to conform to a variety of body types. The struggle to obtain accurate information from the compass ended up taking up too much of our time, and was abandoned in favor of the Android compass, which was already functional at the time. An external compass would be an addition well worth investigating in the future. It would allow the option of the user turning on the navigation, then putting the phone in a pocket or a bag, making the application completely hands-free.

CONCLUSION AND FUTURE WORK

We have designed a navigation system, HaptiGo, which uses tactile feedback to communicate directional information. We developed a wearable harness which delivers the vibrational feedback to the user. The positioning of the actuators and the minimalistic approach to the hardware makes this system one of the most intuitive tactile navigation systems created as of yet. The affordable hardware and utilization of smart phone technology for computing makes HaptiGo a more accessible system than previous tactile navigation systems. We have experimented with this system for use with walking tours and short driving tours on small roads. Based on our experimentation, we are confident in saying that this systems intuitive and precise nature yields more accurate paths of travel in comparison to traditional forms of navigation using visual aids. We believe that tactile navigation could become more commonplace in the future, if people are given time to become accustomed to such methods.

An improvement to be made in the future is the addition of an external compass to make HaptiGo completely hands-free. HaptiGo would require less of the users attention, allowing for multitasking during the navigation process, and an even more unobtrusive application.

In the future, we would also like to test our application on the blind. A possible study would be a comparison between the data collected from the blind and the data collected in this experiment. It would be intriguing to see if the blind could navigate just as efficiently with HaptiGo, if not more so, than those whose vision is intact.

REFERENCES

[1] B. Davis, Effect of tactical navigation display modality on navigation performance, situation awareness, and mental workload, in Proc. HFES Ann. Meeting, Santa Monica, CA, 2006, pp. 20892093

[2] K. Tsukada and M. Yasumrua. Activebelt: Belt-type wearable tactile display for directional navigation. In Proceedings of UbiComp2004, pages 384–399. Springer LNCS 3205, 2004.

[3] Thomas B, Demczuk V, Piekarski W, Hepworth D, Gunther B. A wearable computer system with augmented reality to support terrestrial navigation. In: Proceedings of ISWC '98 (Second International Symposium on Wearable Computers). Pittsburgh, PA, October 19-20, 1998. p. 168-171.

[4] Feiner, S., MacIntyre, B., Hollerer, T. and Webster, A.: A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment,Proceedings of First International Symposium on Wearable Computers (ISWC97), pp. 7481 (1997).

[5] Martin Pielot , Niels Henze , Wilko Heuten , Susanne Boll, Evaluation of Continuous Direction Encoding with Tactile Belts, Proceedings of the 3rd international workshop on Haptic and Audio Interaction Design, September 15-16, 2008, Jyvskyl, Finland

[6] D. Wagner and D. Schmalstieg. First Steps towards Handheld Augmented Reality. In Proceedings of International Conference on Wearable Computers, pp. 127137. Los Alamitos, CA: IEEE Press, 2003.

[7] Michael Rohs , Johannes Schning , Martin Raubal , Georg Essl , Antonio Krger, Map navigation with mobile devices: virtual versus physical movement with and without visual context, Proceedings of the 9th international conference on Multimodal interfaces, November 12-15, 2007, Nagoya, Aichi, Japan

[8] Krausman, A., Elliott, L., Redden, E. and Petrov, P. Effects of Visual, Auditory, and Tactile Cues on Army Platoon Leader Decision Making. In Proc. ICCRTS 2005 (ARL-TR-3633), U.S. Army Research Laboratory (2005), 2–8.

[9] Krausman, A., Elliott, L., Redden, E. and Petrov, P. Effects of Visual, Auditory, and Tactile Cues on Army Platoon Leader Decision Making. In Proc. ICCRTS 2005 (ARL-TR-3633), U.S. Army Research Laboratory (2005), 2–8.

[10] Tactile stimulation of the human head for information display Gilliland, K. and Schlegel, R.E. (1994). Tactile stimulation of the human head for information display. Human Factors, 36(4), 700-717.

[11] Jones, L. A.,& Nakamura, M. Haptic displays: the tactile vest. In Proceedings of the Collaborative Technology Alliances Conference, 2003.

[12] Bossman, S., Groenendaal, B., Findlater, J. W., Visser, T., de Graaf, M. and Markopoulos, P.: Gentleguide: An exploration of haptic output for pedestrian guidance, Proceedings of the Mobile HCI, 8-10-2003, Springer Publications, pp. 358362 (2003).

[13] Tan, H. and Pentland, A.: Tactual Displays for Wearable Computing, Personal Technologies, Vol. 1, pp. 225230 (1997).

[14] : van Veen, H. and van Erp, J. B. F.: Tactile information presentation in the cockpit,Haptic Human-Computer Interaction, Vol. 2058 , Springer Publications, pp. 174 181 (2001).

[15] Wilko Heuten , Niels Henze , Susanne Boll , Martin Pielot, Tactile wayfinder: a non-visual support system for wayfinding, Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges, October 20-22, 2008, Lund, Sweden

[16] Nanja J. J. M. Smets , Guido M. te Brake , Mark A. Neerincx , Jasper Lindenberg, Effects of mobile map orientation and tactile feedback on navigation speed and situation awareness, Proceedings of the 10th international conference on Human computer interaction with mobile devices and services, September 02-05, 2008, Amsterdam, The Netherlands

[17]Van Erp, J.B.F. and Duistermaat, M. 2005. Tactile guidance for land navigation. Technical report: TNO-DV3 2005-C 013 Soesterberg, The Netherlands: TNO Human Factors Research Institute.

[18] J. B. F. V. Erp, H. A. H. C. V. Veen, C. Jansen, and T. Dobbins. Waypoint navigation with a vibrotactile waist belt. ACM Trans. Appl. Percept., 2(2):106117, 2005.