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GPS Waypoint Navigation via Head Mounted Vibrotactor

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Abstract—**The purpose of this project was to create a mode of pedestrian navigation via a single head mounted vibrotactor. Our intention was to achieve accurate waypoint navigation with fewer tactors than in previous works, thereby introducing a simpler system and increasing cost effectiveness. Test results concluded that average walking speeds through our course were similar when given verbal direction and when utilizing the head mounted system.**

I. INTRODUCTION

Vibrotactile displays have the potential to aid users with visual impairments or subjects who don't know the direction to their destination. These displays can also be utilized to improve safety in situations involving high visual workloads. Driving, for example, requires the full attention of the operator for peak performance and safety. The addition of a visual navigation display, while helpful, also serves to reduce safety. The addition of another sensory channel, in this case touch, can alleviate the stress of a predominately single sense task.

A. Background

In an investigation to prove the value of vibration in navigation, Van Erp [2] mounted eight tactors in a driver seat within a simulator. The study found that compared to a visual display, a tactile display reduced the driver's workload, especially in the high workload simulation. The incorporation of both displays simultaneously offered the greatest reduction in driver's workload suggesting it to be the safest system. Pedestrian navigation is typically conducted visually through the use of signage and verbal directions. In environments of low visibility, (i.e., deep diving, inclimate weather, fog of war) additional sensory feedback may offer drastically improved performance. Bosman et al. [1] used wrist mounted tactors to provide low resolution indoor navigational feedback to pedestrians. Subjects using signage were more likely to make errors than with the use of the GentleGuide (wrist tactors). A similar system with higher resolution was developed for a study involving waypoint navigation, first in pedestrians then followed by vehicle operators. This system took the form of a vibrotactile waist belt with a resolution of 45 degrees. Van Erp [3] found that while using the belt, pedestrian walking speeds were slightly slower than normal walking pace, however the belt was still considered successful as all participants completed the courses without issue. The case studies that followed proved the vibrotactile belt's effectiveness in navigation beyond pedestrian use as well. Vibrotactile displays offer increases in performance and safety most notably when used in situations involving heavy workloads. By incorporating these displays with other sensory feedback, users can allocate more attention to the task at hand, ultimately leading to higher safety and performance.

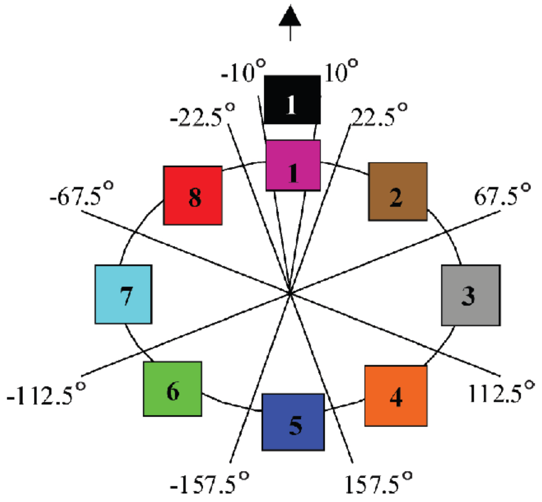

Fig 1. Example of a waist belt system using multiple tactors to display navigational information. Each tactor covers a 45 degree window. Our system uses a single head mounted tactor.[3]

II. METHODS

A. System

The system was purpose built with cost and simplicity as major priorities. The navigation system consisted of readily available commercial parts. The electronics package contained a 32 kbit microcontroller with read only memory, a magnetometer and a GPS receiver. A vibrotactor was mounted at the front of a helmet; the helmet also served as the mounting base for the electronics package so as to offer maximum satellite reception. With the implementation of a single tactor, a body mount would decrease the user's ability to move fluidly, so a head mount was chosen to give the user the ability to probe for a waypoint without having to turn his/her entire body. Power was delivered via a

Fig. 2. User wearing the GPS navigation system

laptop within a backpack worn by the user. It was possible, however, to power this system with a more compact and lightweight onboard power supply. This system allowed the device to sense not only the location of the user, but also the direction of the magnetometer. It was deemed necessary to incorporate a magnetometer as such as opposed to merely using GPS course-track for heading such that a user could get meaningful feedback from the device while standing still as well while moving.

B. Distance and Direction Feedback

Directional information, in a haptic sense, can be transmitted to a user in various ways. Frequency, amplitude, timing, and location are parameters that can be used to convey information to a subject [3]. By using a single tactor, location is not an option as there is only one vibrating locale. Ultimately, the use of varying amplitude was decided on to direct the user as it was best suited for the particular hardware used. To determine the correct path, a user would feel a vibration when on a proper heading. The proper heading was determined by a forward facing cone that varied in width depending on distance to the waypoint. The maximum width of the cone was 60 degrees at 1000m from the waypoint. This cone decreased linearly down to a 10 degree cone at 10m from the waypoint. This decrease allowed for the user to hone in on a waypoint as he/she got closer. Also, this provided some feedback to the user as to their distance from the current waypoint. The vibration intensity was controlled by variable voltage to the vibrotactor. When on a perfectly aligned path, the user would feel the most intense vibration (given by 3.3V to the tactor). The voltage decreased linearly toward the outer portion of the cone, where the voltage was set to the lowest noticeable vibration. If the user was outside of the cone, no voltage was sent to the tactor, resulting in no vibration.

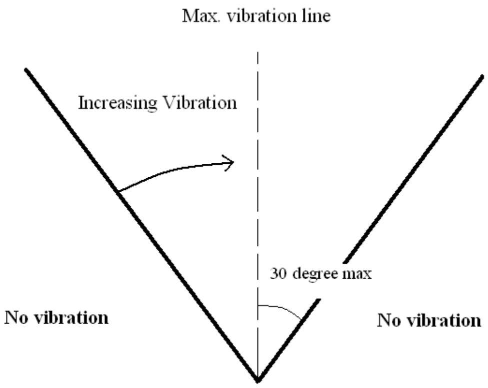

Fig. 2. Top down view of cone of vibration

C. Test Subjects

Six subjects were tested, three male and three female ranging from seventeen to 50+. The three female subjects were 50+, preferring not to give their age. Subjects were unpaid volunteers in good overall health.

III. DATA COLLECTION

Data was collected in order to assess the effectiveness of our haptic guidance system. These tests were conducted on the same city block for all

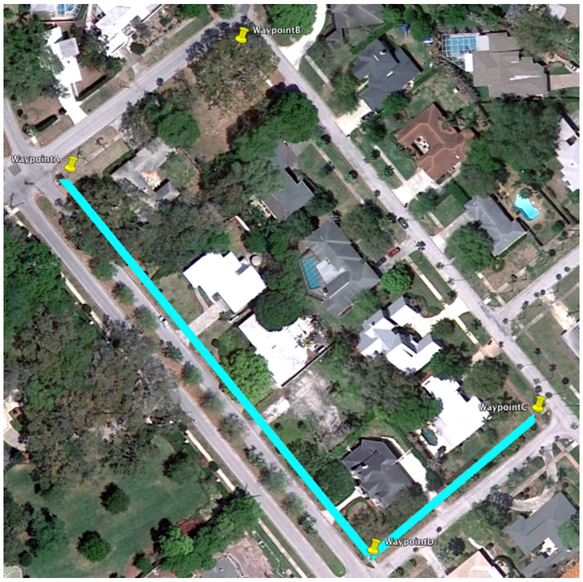

Fig. 3. Google maps was used to determine GPS coordinates

participants. The haptic device was set to guide participants to waypoints preset at the corners of this city block (at the junction of sidewalks).The participants were fitted with the haptic guidance hardware consisting of a helmet and a backpack. Each participant was tested individually and in isolation from the others. Three trial types were tested; they were as follows:

A. Trial 1

The participants were given directions corresponding to a knight's move (one short length followed by or preceding one long length of the rectangle) and asked to complete that known course. No haptic guidance was provided in this trial in order to establish a baseline for their individual walking speeds. Participants were encouraged to walk at the same individual pace throughout their testing.

B. Trial 2

Another random knight's move path was designated, and the participants were given directions such that they could complete the course without additional guidance as was the case in the first trial. However, in this case, haptic guidance was provided. This served as a familiarization trial. It should be noted that in some cases, participants took extra time to complete this trial (in comparison with the others) as they took their time in familiarizing themselves with the device.

C. Trial 3

In the final test, another random knight's move path was programmed into the device, but directions were not given to the participants. The participants were then asked to navigate to two consecutive waypoints without any assistance except that of the haptic device.

IV. RESULTS

Trial 1, the control trial, had an average walking time of 2:45 among all participants with a standard deviation of 20.34 seconds. As a familiarization trial, trial two was omitted from statistical analysis. Trial three average walking times were 2:57 with a standard deviation of 26 seconds. The difference between trial one and three times was less than twenty seconds for all but one subject. The average time disparity between trial one and three was 14.66 seconds with a significant portion of this coming from participant 6. Participants 2 and 4 were the only subject to walk the course faster using only the navigation system.

Participant #	**Data by Trial Type**
1	Trial 1: 2:23.85 Trial 2: 3:11.23 Trial 3: 2:29.79
2	Trial 1: 2:35.67 Trial 2: 2:44.25 Trial 3: 2:34.90
3	Trial 1: 2:42.11 Trial 2: 2:59.33 Trial 3: 2:57.78
4	Trial 1: 2:59.10 Trial 2: 2:44.71 Trial 3: 2:50.50
5	Trial 1: 3:20.88 Trial 2: 3:33.03 Trial 3: 3:38.85
6	Trial 1: 2:37.18 Trial 2: 2:43.89 Trial 3: 3:16.94

Table 1. Trial times by participant (min:sec)

V. DISCUSSION

Excluding subject 6, the average walking time differences between trial one and three was only 9 seconds. This translates to a 5.4% increase in walking times. The inclusion of subject 6 bumps this value to 8.8% for the group. It’s possible that the GPS tracking was at fault for the large disparity for this participant, as her familiarization times were significantly faster. All subjects except one took longer to walk the course in trial three suggesting that further familiarization could lead to faster times with the navigation system. Feedback from the subjects was mostly positive. Most notably, subjects enjoyed the novelty factor of the head mounted vibrotactor. Subjects had no issues with going significantly off coarse and found the system to be helpful and enjoyable. The main critique of the system was the lack of a verifying signal upon reaching a waypoint. Another issue voiced was the non silent tactor. In some cases, the fit of the helmet used was such that pressure on our tactor prevented it from vibrating properly. This was likely due to the fact that our tactor was an electric motor with an exposed eccentric mass. Because of the exposed rotating element, it was possible because of its mounting location for its rotation to have been hampered based on the fit of the helmet.

VI. CONCLUSIONS AND FUTURE WORK

A. Conclusions

The system was considered a success as it achieved what the authors set out to accomplish. The GPS navigation system reliably guided users to successive waypoints while being cost effective and simple. Walking times with and without the navigation system were remarkably close for most test subjects. The time it took to give directions was not recorded, but in a situation that users had only directions to go by, it is entirely possible that a user with waypoint navigation would finish the given course more quickly, especially given more waypoints.

B. Future Work

Thanks to feedback from users, various future improvements to the haptic navigation system can be made. The most helpful inclusion to the system would be an indication upon reaching a waypoint. The current system simply directs the user to the next programmed waypoint immediately after successful waypoint discovery. This could be indicated by a special pattern of vibration signals or with an auxiliary system such as auditory feedback. Also, in order to solve the issue of clearance for our tactor (which was affected by improper helmet fit), a purpose-built tactor that had no such exposed rotating elements would be more desirable. As a proof of concept, the system only required read only memory for the GPS coordinates, however, for future applications, a more interactive system may be desired. Other improvements include a quieter tactor, a more compact package, and the inclusion of timing into the tactor to give a more specific indication of the user's distance from a waypoint. Yet another direction for future work would be the use of such a device for navigating along discretized model of a continuous, curved path. While the current device is technically capable of handling the large series of waypoints required in order to implement a virtually continuous path, the method of detecting whether or not an individual waypoint has been reached would have to be optimized for such an application.

VII. ACKNOWLEDGMENTS

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