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Haptic System for Eyes Free and Hands Free Pedestrian Navigation

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Abstract—**Until now, Augmented Reality was mainly associated with visual augmentation which was often reduced to superimposing a virtual object on to a real world. We present in this document a vibro-tactile system called HaptiNav, which illustrates the concept of Haptic Augmented Reality. We use the haptic feedback method to send users information about their direction, thus enabling them to reach their destination. To do so, we use a turn by turn metaphor which consists of dividing the route into many reference points. In order to assess the performances of the HaptiNav system, we carry out an experimental study in which we compare it to both Google Maps Audio and Pocket Navigator systems. The results show that there is no significant difference between HaptiNav and Google Maps Audio in terms of performance, physical load and time. However, statistical analysis of the mental load, frustration and effort highlights the advantages of HaptiNav compared to two other systems. In the light of the results obtained, we present possible improvements for HaptiNav and describe its second prototype, at the end of this paper.**

Keywords; haptic navigation; augmented reality; mobile computing; human computer interaction.

I. INTRODUCTION

Until now Augmented Reality was mainly associated with visual augmentation, which is often reduced to superimposing a virtual object onto a real object [5]. However, the concept of Augmented Reality is not limited to sight and could be extended to other senses, ie., hearing, smell and touch. Panagiotis et al. [10] classed user experience input and output, in an augmented reality environment. The input may be audio, visual, tactile or kinaesthetic, whilst the output may only be visual, haptic or audio. In B.Bayart [6] presented three different existing taxonomies for Augmented Reality, and studied their direct extension in terms of augmented haptics. As a continuation, the Haptic Augmented Reality taxonomy was introduced and separated into two categories: augmented haptics and haptic augmentation. As with the classification of Fuchs et al. [4], Haptic Augmented Reality systems can be used either to augment existing data or to add information, referred to as enhanced haptics and haptic enhancing respectively. Enhanced haptics is defined as when the haptic modality amplifies or modulates a haptic datum sent back to the user. In some applications, it may be important to be able to touch data which are not on a human scale and which are not perceptible by direct contact with one of the body parts. Thus, feeling holes and bumps which are no larger than on a mesoscopic scale, a sort of haptic microscope, is an example of this. The concept of haptic enhancing can be summarized as scenarios where the haptic modality is used to send additional information to the user. Some researchers have explored the possibilities of transferring emotions through haptic interfaces. Shneiderman [13] defined a (computer) icon as an image, a drawing or a symbol representing a concept, and in 2004 S. A. Brewster et al. [7] introduced the notion of tacton or tactile icon which is like visual icons, represents a tactile concept. After analyzing the possibilities provided by tacton vibrations in [8], the work presented in [16], endeavors to go further by trying to simulate emotions through tactile vibrations.

In the study presented in this paper, we explore how to use Augmented Reality in its haptic modality, in order to guide pedestrian in a new urban environment. In this context, several questions are raised: Is the haptic modality efficient enough to guide pedestrians? Is it robust enough to allow hands free and eyes free navigation? To answer these questions we implement a vibro-tactile system which illustrates the concept of haptic augmented reality. We use the haptic modality to send users informations about their directions, enabling them to reach their destinations. In the first Section of this paper, we describe the prototype developed for HaptiNav. We then present the software structure of HaptiNav and the algorithm used. In Section 4, we detail the experimental study carried out to assess performances of HaptiNav system, in comparison with the standard Google Maps Audio and with another vibro-tactile system. All of these systems were tested without any visual support. At the end of this paper, we present possible improvements for HaptiNav and describe the second prototype for our system.

II. DESIGN OF THE HAPTIC INTERFACE

The Figure 2 highlights three possible prototypes for our system. The selection criterion consists of finding the prototype which provides user friendly navigation, which enable users to navigate hands free and eyes free.

We carry out a comparative study to choose the prototype which best corresponded to our selection criterion. The first line in Figure 2, shows a tactile tablet designed to be placed in the palm of the hand. Jin et al. [9] created a tactile tablet made up of 12 panels, each panel contains a tactor (ie., a vibrating motor). Their tactile tablet contains 12 vibrators, forming a 4 lines and 3 columns matrix. In order to send to user spatial and directional information, T-mobile system [9] combines three vibrators. For instance, T-mobile system makes tactors vibrate in the first line

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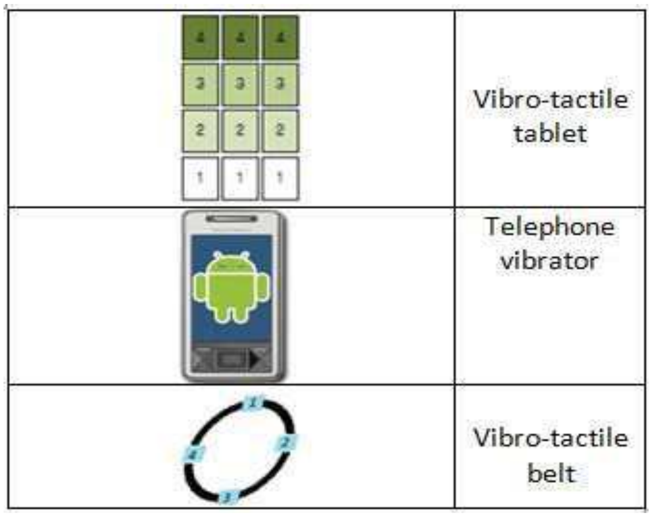

Figure 1. Possible prototypes.

to show the north. The main disadvantage of this prototype is that it needs to be held in one of the user's hands, therefore it prevents hands free navigation. The second prototype is based on a single vibrator integrated in a mobile phone. The Pocket Navigator system [3] uses this prototype; it codes the direction which must be followed by the user in different vibration modes, known as tactons. The approach presented in Pocket Navigator uses three different rhythms to tell the user to go straight on, turn right, turn left or stop. As shown in the figure below, the system translates the action of going straight on by two short successive pulses, turning left by a long vibration followed by a short one, turning right by a short vibration followed by a long one and turning back by three short pulses.

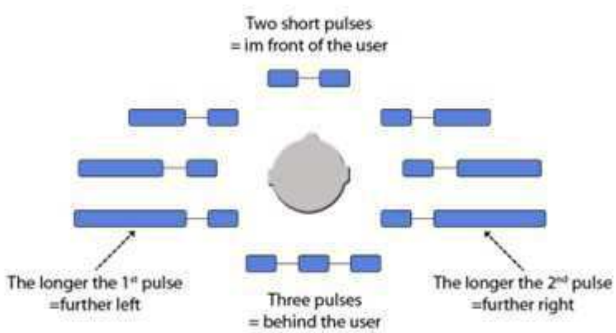

Figure 2. Pocket Navigator tactile diagram [3].

We chose to develop the vibro-tactile belt prototype, namely to make navigation more user-friendly. As previously highlighted, we want users to be able to reach their destinations without using vision or hands. The aim behind this choice is to enable users to concentrate on road traffic and obstacles, rather than on the navigation system. For people visiting a town for the first time, the advantage is that it guides them whilst at the same time, allowing them to fully concentrate on the new environment. Unlike ActiveBelt [15], our system has four vibrators.

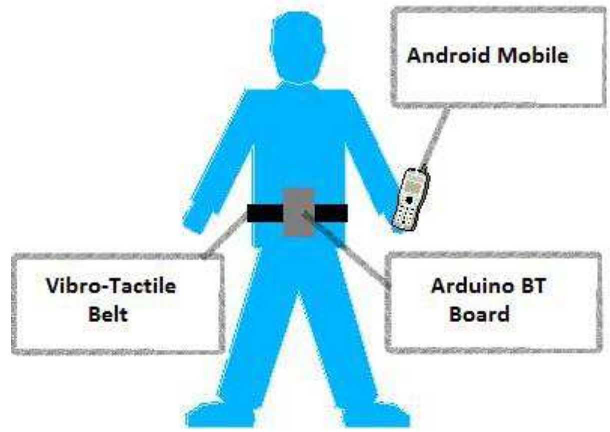

Figure 3. Prototype of HaptiNav.

III. IMPLEMENTATION

Our system called HaptiNav, consists of an Android Smartphone Galaxy S2 and an Arduino BT electronic board [1] as shown in Figure 4. Arduino BT is an Arduino board with an integrated Bluetooth module, thus enabling wireless communication with the smartphone. In order to implement the system's applicative aspect (deployed on the mobile and the Arduino board), we use Android SDK programming interface (API) and Arduino software.

The Android development environment consists of the Android development tool (ADT) integrated in Eclipse. We use Arduino freeware to develop the application loaded on the Arduino BT board, which controls the vibrators and the microcontroller. We chose this software because it is the proprietary platform of the Arduino electronic card.

To make the mobile application and the Arduino sketch communicate, we use Amarino software interface. It is developed as part of the Android meet Arduino project [2]. Amarino was launched by Bonifaz Kaufmann [2] in 2009, and developed at the University of Klagenfurt in Austria. There is another tool which enables Android and Arduino to communicate via USB: ADK (Android Open Accessory Development Kit). We are unable to adopt this solution since it is only available for Android version 13. However, Galaxy S2 has Android version 11. The diagram below shows the structure of the applicative part of our system. It is divided into three modules: Android, Arduino and Android Arduino interface. The Android application constantly calculates the difference between the user's orientation and the orientation of the route's closest way point. The Android application sends difference in orientation angle to the Arduino sketch through the Amarino plug-in. Consequently, the Arduino sketch activates the belts vibrator corresponding to the direction sent.

IV. ALGORITHM IMPLEMENTED

Unlike the compass metaphor used in ActiveBelt [11], we use another metaphor which we shall refer to it as turn by turn metaphor. With the compass metaphor, the difference between the user's current orientation and the destination's orientation is

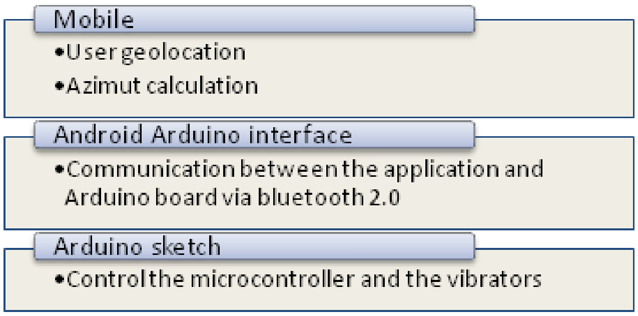

Figure 4. Structure of the system's applicative part.

instantly calculated and then, the user is constantly redirected towards the final destination. The turn by turn metaphor consists of dividing the route into many reference points. Thus, the system shows the user which direction to take for each way point. We refer to the user's current orientation as OC and the desired orientation as OD. The desired orientation OD is extracted from the KML file (Keyhole Markup Language), generated by Google Maps. Desired orientation can be found in the tag <heading> of the kml file. A change in orientation OT (the angle required to go from the current orientation to the desired orientation) is obtained by calculating the difference between OD and OC.

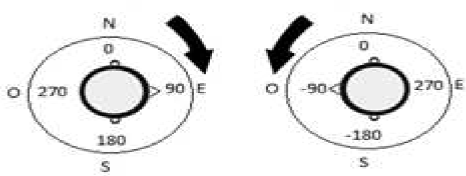

Figure 5. Change of orientation.

$$OT = OD - OC$$

Since

$$0 <= OD < 360$$

and

$$0 <= OC < 360$$

we therefore have :

$$-360 < OT < 360$$

Thus, two cases can be illustrated:

(a) When the user has to move clockwise,

$$(0 <= OT < 360)$$

(b) When the user has to move anti-clockwise.

$$(-360 < OT < 0)$$

Both cases are illustrated in figure 5.

V. EXPERIMENTAL STUDY

There are several systems with which we can compare our system described above. We omit the work presented by Lin et al. [12], since their system indicates only two directions (left and right). We chose to compare our system with standard Google Maps Audio (pedestrian version) and with Pocket navigator [6]. Both applications were installed in Samsung S2 equipped with Android version 2.3. Google Maps Audio is a very popular application. Pocket Navigator is a vibro-tactile system for pedestrian navigation whose principle is described in the first Section of this paper.

Figure 6. Experiment with HaptiNav

A. *Protocol*

In the experimental study, we carry out three experiments. We vary the navigation mode between the three experiments. The first consists of navigating in audio mode using Google Maps Audio. The second experiment consists of navigating with our own system in a vibro-tactile mode. The third one consists of navigating with Pocket navigator in a vibro-tactile mode. We keep the same route (figure 7) in the three experiments, since each experiment has 12 different participants. The experiments take place at the School of Advanced Industrial Technologies located at Izarbel Science Park. Each subject takes part only in one of the three experiments and is followed by two experimenters. One experimenter managed the dashboard, the other managed the stopwatch. Subjects were not allowed to look at the Smartphone's screen or ask the experimenters questions. They had to walk at their usual speed which is about 1 meter per second. There was no learning phase prior to the experiments.

B. *Participants*

36 unpaid subjects, 18 female and 18 male, take part in the experimental study. All are ESTIA students, trainees or employees. They are aged between 22 and 39 years old (average =30.5). The 36 subjects are divided into three groups, each with 12 subjects. The first, second and third group take part respectively in the first, second and third experiment. It is worth noting that none of the subjects is involved in the research work presented in this paper. All the users have already used a map and 35 out of 36 are used to using electronic navigation systems, such as Tom-tom. Two subjects are unfamiliar with the experiment's location; the others have already been there. However, knowing the location was not a significant factor since subjects only find out the route to destination at the end of the experiment.

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Figure 7. Izarbel Science Park route.

C. Quantitative study

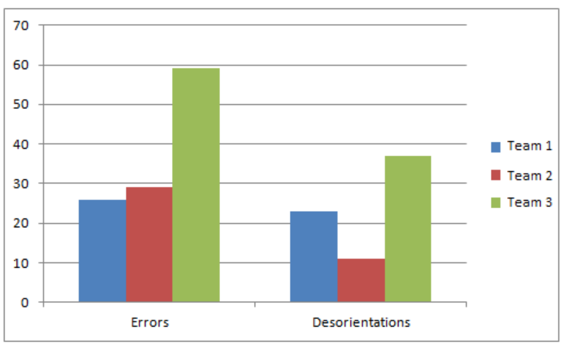

Figure 8. errors and disorientations rates.

The results of the experimental study show that the three techniques can be efficiently used for navigating. Figure 8 shows the number of navigation errors as well as the number of disorientation events. An error is recorded when subjects did not take the right direction with regard to a way point (different from that given by the navigation system). A way point is schematized in Figure 7 by a blue arrow.

A disorientation event is noted when a subject stops or deviates from the simplified route in figure 6 for more than 10 seconds. A disorientation event is also noted when a subject indicates to the experimenter that he is confused. After a navigation error or a disorientation event, the subject is redirected towards the right direction. HaptiNav and Google Maps Audio have a very similar number of errors, 29 and 27 respectively. However, disorientations with Google Maps Audio occur twice as often as disorientations with HaptiNav. They happen with Pocket Navigator three times as often as with HaptiNav. Navigation errors of Pocket Navigator occur more than twice as often as navigation errors of HaptiNav and Google Maps audio. Navigation errors with HaptiNav and Pocket Navigator, take place when the vibro-tactile signal is not understood or due to errors relating to the GPS or digital compass. Navigation errors take place with Google Maps Audio due to GPS errors. Figure 7 shows the number of navigation errors and the number of disorientation events related to the three studied systems.

Figure 9 shows the comparison of averages between the groups in terms of errors. The smallest error recorded for HaptiNav is 0. However, the smallest error recorded for Pocket Navigator is 4.

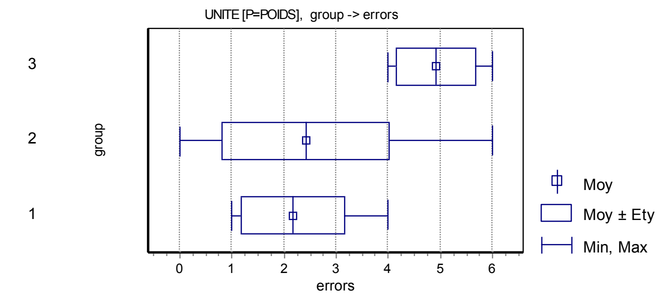

Figure 9. Diagram of averages relating to errors.

Since the ANOVA test gives a value of p equal to 0.6641 ($p=0.6641>0.5$), we conclude that there is no difference between the errors averages of the first and the second experiment. We establish the fact that the performances of HaptiNav are close to those of Google Maps Audio. The ANOVA test gives a p value equal to 0.0001($p=0.0001<0.5$) for the second and third experiment. We therefore conclude that HaptiNav is better than Pocket Navigator in terms of navigation errors.

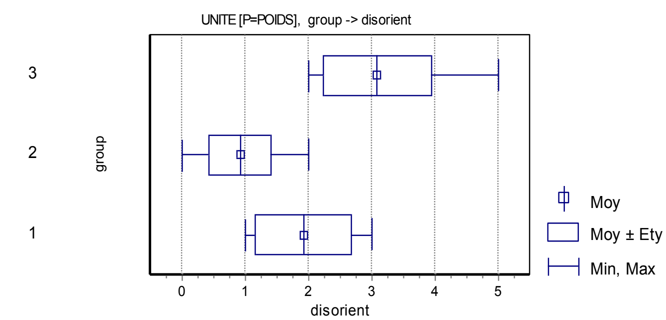

Figure 10. Diagram showing average number of disorientations.

Figure 10 shows the comparison of averages between the groups in terms of disorientation events. Since the value of p ($p = 0.0014 < 0.05$) is below the significance level of 0.05, there is therefore a significant difference between HaptiNav and Google Maps Audio. This enables us to confirm the hypothesis that HaptiNav is more efficient than Google Maps Audio in terms of reducing disorientations during navigation. The ANOVA test highlights a significant difference between Google Maps Audio and Pocket Navigator ($p =0.0028 <0.05$). Hence, the PocketNavigator system generates more disorientations events than Google Maps Audio.

Since the value of p ($p = 0.0014 < 0.05$) is below the significance level of 0.05, there is therefore a significant difference between HaptiNav and Google Maps Audio. This enables us to confirm the hypothesis that HaptiNav is more efficient than Google Maps Audio in terms of reducing disorientations during navigation.

D. *Qualitative study*

Subjective estimation of workload is measured using the Nasa TLX Load Index test. This is a multidimensional evaluation test in the form of weightings and it is applied to the measurement of six specific load factors: mental effort, time spent, frustration, physical load, performance and effort. Subjects note the system studied by attributing a mark from 0 to 20 for each factor. No significant difference is detected between HaptiNav and Google Maps Audio in terms of physical load, time spent or performance ($p = 0.68 > 0.05$). However, statistical analysis of perceived mental load, frustration and effort dedicated to the task, highlights the advantage of HaptiNav ($p < 0.05$) with regard to Google Maps Audio and Pocket Navigator. These results show that the mental effort perceived by subjects to understand HaptiNav's vibro-tactile instructions, is on average equal to 4.5 points, which did not affect the frustration felt with this system. However, Pocket Navigator is rated with the highest level of frustration. The average of frustration with this system is 17.84 points.

We ask the following question to the second group of subjects (subjects who take part in the navigation experiment with HaptiNav): "Would you accept wearing this belt to find your way around a town which you are visiting for the first time?" 41 % say they would not, which means that 5 of the 12 subjects questioned would refuse to wear the HaptiNav tactile belt system when visiting a town for the first time. These participants explain that they do not like to wear a belt in town because they do not want to be noticed by other pedestrians. They suggest that this system could be smaller. We ask the following question to the third group of subjects (subjects who take part in the navigation experiment with Pocket Navigator): "Would you accept using Pocket Navigator to find your way around a town which you are visiting for the first time?" More than 80% say that they would not because Pocket Navigator is very inaccurate. We ask this question to the first group of subjects (subjects who take part in the navigation experiment with Google Maps Audio): "Would you accept using Google Maps Audio to find your way around a town which you are visiting for the first time?" More than 80% said that they would only if Google Maps Audio is turned in graphic mode in addition to audio mode.

E. *Discussion*

The obtained results confirm that the HaptiNav system can be used for hands free and eyes free navigation. We consider improving the quality and the intensity of vibrations in the second prototype of HaptiNav system. Indeed, the participants notice that vibrations became difficult to distinguish when the system's belt is worn on top of thick clothes. This issue explains some of navigation errors happened with HaptiNav.

Some participants say that they refuse to wear HaptiNav because of the belt. So, we will replace the belt with a bracelet which can be worn around the wrist [14], in our System's second prototype.

VI. CONCLUSION AND FUTURE WORK

In this paper, we have presented an haptic system "HaptiNav" which can be used to guide users to their destination.The aim of our research is to determine whether augmented reality in haptic modality can be used to ensure hands-free and eyes-free navigation in an urban environment. In order to answer this question, we test our system with people with normal vision. We compare it to Google Maps Audio and to Pocket Navigator systems, to evaluate its performance.

With HaptiNav, all subjects manage to reach their destinations. HaptiNav and Google Maps Audio systems have approximately the same error rate. However, HaptiNav has the advantage of reducing the number of disorientations. In addition, a statistical analysis of the mental workload, frustration and effort highlights the advantage of HaptiNav, compared to Google Maps Audio and Pocket Navigator. These results show the performance of HaptiNav. Some of participants said that they refuse to wear HaptiNav because of the belt. To overcome this problem, we will replace the belt with a bracelet which can be worn around the wrist, in our System's second prototype. We envisage developing our system, so that the new prototype can support navigation by the visually impaired, in an urban environment. We intend to add a proximity sensor to this system, in order to detect obstacles along the route for the visually impaired. We also plan to add a movement sensor to reintroduce the perception of movement lost by visually impaired people.

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