Tactile Feedback to Aid Blind Users of Mobile Guides

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ABSTRACT
In this work, we investigate how using the haptic channel as a complement to the audio/vocal one can provide better support for the use of mobile museum guides for blind users. The aim is to improve autonomy and social integration of blind visitors. Based on our previous experience in mobile guide design, the proposed solution aims to add tactile feedback enhancement for orientation support and obstacle avoidance.

Categories and Subject Descriptors
H.5.2 User Interfaces

General Terms
Design, Experimentation, Human Factors.

Keywords
Mobile guide, accessibility, blind, haptic feedback.

1. INTRODUCTION
Technological support is increasingly used to provide services and products that are more suitable for a wide variety of users in several different contexts. Technologies also provide new opportunities to allow users with special needs – such as people with disabilities – to access or perform activities previously impossible or particularly difficult to do (e.g. accessing digital information for blind people). However, to achieve such a result accessibility principles should be applied when developing a product or service.

Accessibility is a general term used to indicate that a product (e.g., device, service, environment) is accessible to as many people as possible, including those with disabilities. Accessibility is an important feature of systems or products to allow users with different abilities to access or use them in a different manner. In this perspective, a multimodal approach can represent a valuable way to support various interaction modes, such as speech, gesture and handwriting for input and spoken prompts. Thus, by combining various interaction modalities it is possible to obtain an interactive user interface suitable for different abilities. For instance, if a mobile application is enriched by vocal support it can become accessible and usable by a person with vision impairment. In brief, multimodal user interfaces have implications for accessibility. A well-designed multimodal application can be used by people with a wide variety of impairments. Visually impaired users rely on the voice modality with some keypad input. Hearing-impaired users rely on the visual modality with some speech input, and so forth.

In this regard, we decided to consider museum environments to investigate how to design and develop a multimodal mobile application, which can be easily used by blind people. To this end, we have designed an accessible and usable mobile guide for museum visits. In order to make it accessible, a specific module for accessibility has been included. The aim of our study is to provide blind visitors with greater autonomy. Even if the blind cannot view museum items, visiting an exhibition autonomously can represent a good way to integrate the vision-impaired into a group (e.g. family or friends) and is more effective than obtaining cultural information from a Web site or multimedia CD.

In particular, in this work we investigate how the haptic channel, in conjunction with the audio/vocal one, can provide better support for the use of mobile museum guides for blind users. People who are blind or visually impaired must rely upon senses other than sight to perceive diverse information (e.g., shape, dimensions, etc.). Haptic interface technology allows building tangible data surfaces to provide an additional modality for data exploration and analysis. Unfortunately, the amount of information that can be perceived through touch is less than that which can be perceived through vision. Consequently, multimodal approaches should be investigated to enhance the perception of blind and visually-impaired people.

The solution proposed herein is based on a previously developed guide, which we have enhanced with tactile feedback. The application is a location-aware museum guide that provides information about visited sections and artworks. Localization, enabled by a grid of RFID (Radio Frequency IDentification) tags, allows the detection and description of artworks in the proximity. The accessible guide also exploits a wearable electronic compass for detecting the user current orientation. While location awareness/orientation can be useful for normal people, it is fundamental to provide direction tips necessary for blind users' mobility. Indeed, we conducted an early evaluation [9], involving 5 blind participants, intended to determine which output (sound effects vs sound effects and vocal tips were considered) would be preferred by blind users for orientation tasks. The results showed a clear preference for the combination of sounds and vocal output. Users declared that the vocal sentences are more intuitive when the system is designed for casual use. However, one user reported that the vocal tips can sometimes become annoying and some users suggested the adoption of a tactile aid.

The criticisms and suggestions we received from the test participants were particularly useful to further develop our work. We provided a first discussion of an early integration of the haptic output only for orientation tasks on the user interface and its evaluation in [10]. The test involved 11 blinds and mainly aimed to determine whether users preferred vocal sentences or haptic messages as output tips. Since no significant preference emerged, we considered the combination of vocal and haptic feedback a reasonable solution.

In this paper we report on an extended use of haptic feedback, also for obstacle avoidance. In particular, in the next section we discuss some relevant related work. Then, the design and implementation for both hardware and software support are also described. Lastly, some concluding remarks along with indications for future work are discussed.

2. RELATED WORK

Many studies on the use of haptic output have already been conducted. For example, [3] deals with *Tactons*, structured vibrotactile messages carrying complex information. These authors studied the use of haptic feedback alone to encode 3 different parameters (*Rhythm*, *Roughness* and *Spatial Location*) exploiting several vibrotactile actuators.

An array of 9 tactile actuators making up a wearable vibrotactile display was evaluated in [13]. The studies mentioned above are related to the use of haptic output alone (without audio) on stationary devices. Mobile interactions supported by tactile output were instead tested in [2]. The tests showed that user performance significantly increases when haptic stimuli are provided to alert her about unwanted operations (e.g. double clicks or slips during text insertion).

Vibrotactile output combined with gesture recognition has also been investigated: examples of how interaction with mobile phones can be enhanced are presented in [4] and in [12]. These works, however, do not specifically treat interfaces for the blind.

The recent progress of handheld computers and mobile phones has enabled the development of compact wearable aid systems for the blind. An example is the RadioVirgilio/Sesamonet [5] guidance system, based on a cane with embedded RFID reader and a Bluetooth module. Sensed data are sent via Bluetooth to the handheld device (which is also connected to a remote server) that guides the user by means of speech-synthesized instructions. However, this solution requires that blind users follow predefined paths, thus limiting the user's freedom of movement. Another example of RFID-enabled navigation for blinds is the proposal of [11]. Detected tags provide the coordinates of their location as well as other information. Orientation of the blind is enabled by vibrotactile output. An interesting novelty is that the system does not depend on a centralized database. However, like RadioVirgilio/Sesamonet, it focuses on navigation through predefined paths indicated by RFID tags. GLIDEO [6] is a solution for providing blind users with audio information about RFID-tagged objects on the environment (such as temperature and weight). The RFID reader is embedded on a glove to let the user freely explore the area. Ubibus [1] is a mobile system conceived for helping blind people in public transportation scenarios. Users may use a mobile device (PDA or mobile phone) with WLAN or Bluetooth connectivity to activate a stop request or to be informed about the next stop.

The authors of [7] describe an assistive system exploiting electronic markers for providing useful information to the visually impaired. Tagged objects are detectable by a mobile device that provides descriptive information.

Although these solutions provide information about the surrounding environment, they do not offer support to assist users in moving towards the tagged objects avoiding potential obstacles. In contrast, our work specifically aims to improve the mobility of blind users for this purpose.

3. ARCHITECTURE

The haptic support discussed here is a capability we have integrated into a multimodal guide, which uses a localization infrastructure based on a number of RFID tags deployed along the exhibition area of the museum. Each tag is placed by an artwork. The artwork-tag relation lies in the museum database. The coordinates of each artwork with respect to the room are also stored in the database: artwork position is essential for suggesting the right direction to the user. Orientation functionalities are enabled by the use of a wearable electronic compass, which is a wireless, battery-operated device.

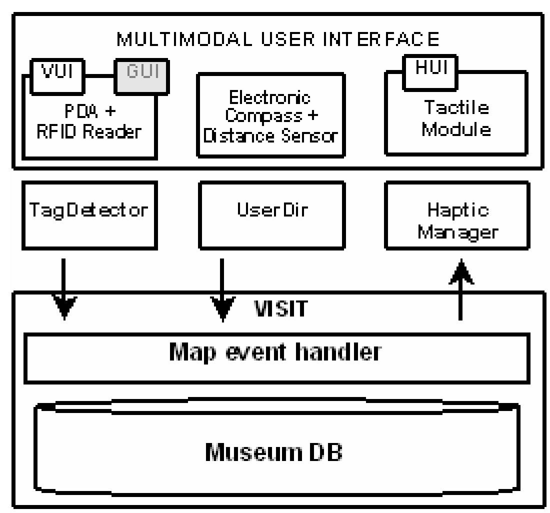

Figure 1. An overview of the mobile guide architecture.

Figure 1 summarizes the architecture of our system. In the diagram we have:

RFID-Reader is a hardware module that detects the RFID tags in the environment. It is a CF (Compact Flash) card plugged into the slot of the handheld device and has been provided by Identec Solutions[1]. Each tag transmits its ID with a constant power level to enable detection within about 5 meters. For each tag the RFID reader also detects its signal power (that is, the RSSI – Received Signal Strength Indication, which depends on how far the tag is), reporting it to the software layer. A location event is triggered

[1] http://www.identecsolutions.com.

when a new RFID tag is detected or when the signal strength of a tag has changed.

Tag Detector is the software that embeds the RFID monitoring thread, which generates location events. It interfaces with the RFID reader through pre-compiled software modules provided by the hardware manufacturer.

VUI (Vocal User Interface) exploits an embedded TTS engine, provided by Loquendo[2], which synthesizes the speech for describing artworks/sections and for giving short direction tips on the fly.

Electronic Compass is the device for sensing user orientation in absolute orientation degrees. The compass is needed because calculating the user motion vector based on the signals detected from the RFID tag network is rather problematic. Since none of the existing commercial solutions seemed to be suitable for a mobile application, we expressly designed and developed the device to meet our requirements. It consists of an analogue compass sensor and a microcontroller that manages ADC (Analogue to Digital Conversion) and data serialization. The compass device is battery operated, has an embedded Bluetooth interface with SPP (Serial Port Profile) and is detected by the PDA as a wireless peripheral. The small size and low weight of the compass device make it easily wearable.

The first prototype could be comfortably worn as a necklace. However, the early tests highlighted that the device often rotated due to user's movements, affecting the orientation detection. On the last version, the device is wearable as a belt or can be attached to the user's belt (see Figs. 5 and 6): in this way the compass sensor is perpendicular to the ground and has the best performance. This device embeds also a distance sensor to detect any obstacle located within one meter by the user.

The distance from the nearest obstacle is encoded on the data transmitted to the PDA. This strategy allows the application to raise real time alerts whenever the user approaches an obstacle.

UserDir is the interface software to the compass device that reads and filters the stream of values. It extracts obstacle distance and computes user direction 30 times per second as a value in the interval [0,359] degrees with respect to the Earth's Magnetic North.

Tactile Module is the vibrotactile device we have developed and that enables the *HUI (Haptic User Interface)*. It furnishes haptic information through two vibrating motors and is battery operated. The fundamental needs we considered to design the haptic module were transportability and ease of wearability. For this reason we opted for a single compact device fixable to the PDA. Since the device is attached to the PDA it is possible to enable the communication via infrared (exploiting the infrared port embedded in the PDA). Infrared detection circuitry is very simple to build and much cheaper than Bluetooth one.

Haptic Manager is the interface software to the tactile module, i.e. a suite of methods to control the vibrating motors in real time via an infrared connection.

Visit supports automatic access to museum info such as artworks and section descriptions.

[2] http://www.loquendo.com.

Map Event Handler is the module that monitors the events triggered by the TagDetector, asks the UserDir for the direction, configures the HapticManager, and queries the Museum DB.

Museum DB is an XML specification of the whole museum data: authors, artworks, sections and associations between artworks and RFID tags. These resources make up a simple GIS (Geographical Information System) that holds enough information (sections geometry and artworks positions) to support a blind user.

GUI (Graphical User Interface) is not relevant to the accessible version of the guide.

3.1 Tactile hardware

The haptic output module, which is an add-on that we have specifically designed and tuned, consists of a plastic box (measuring 70 x 50 x 15 mm) fixed to the back of the PDA and of two vibrating motors. Each motor is connected to the box by a 10 cm wire and is attached to a rigid plastic surface of about 1 cm^2. The motors can be fixed to any two fingers by Velcro strips so that the rigid surfaces transmit vibrations to the fingertips. Separating the motors from the box facilitates distinguishing the channels. Otherwise, if motors were attached to the box it would have been very difficult to insulate them and the vibration of a single motor would have propagated to the rest of the device, making harder for the user to distinguish the vibrating side.

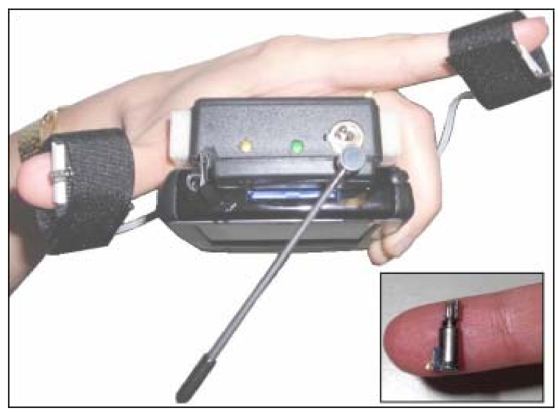

Figure 2. iPAQ handheld equipped with the tactile module and a one of the vibrating motors adopted by the prototype (bottom-right).

3.1.1 Main requirements

The fundamental needs for our haptic module were transportability (limited size and weight), ease of wearability and, of course, the compatibility with PDAs. We chose the infrared standard (IrDA – IrPHY) for interfacing in order to avoid complexity of the circuit. Adopting widely used components such as Microchip controller and potentiometers also reduces the hardware costs.

3.1.2 Circuitry specifications

The main circuit, contained on the box, is able to detect infrared signals since the receiver (infrared photodiode) protrudes from the box and is aligned with the infrared port of the PDA. The circuitry is powered by 3 AAA batteries and drives two vibrotactile actuators according to the commands sent by the PDA via the infrared interface. The actuators are RMV (Rotary Mass Vibrator) recovered from mobile phones (see Fig. 2). Each motor is controlled by the driver circuitry independently. The commands coming from the PDA encode the haptic interface state, that is, for each motor, the on/off flag and the vibration frequency value. The flag controls the switch while the intensity value is transmitted as a byte to a DPP (Digital Programmable Potentiometer) with 256 steps.

The haptic module circuitry is managed by a microcontroller with 4 Mhz clock, whose routine is able to decode a command and to upload the motor states up to 60 times per second.

3.2 Integration of the tactile module

To change the haptic device state, the PDA software application has to determine and send a 3-byte command with the switch flags, the intensity values and some check bits. For example, a haptic feedback such as a short, intense left-side vibration requires two commands. The first, with left flag = 1, right flag = 0, left speed = 255 (the maximum value) and right speed ignored initiates the left engine fast vibration. The second command, with left flag = 0, right flag = 0, left/right speed ignored stops the motor. The vibration duration depends on the delay between the start and the stop commands. A complex haptic feedback such as a left-right fading can be created by repeatedly sending commands where the left speed parameter decreases and the right one increases (or vice versa). Since the latency between the *sendCommand* function call and the new configuration of the two motors is about 15 ms, even more complex effects may be created, such as the rhythms discussed in [3].

3.2.1 *Complex vibrating sequences*

Figure 4 summarizes the architecture of our haptic support. The mobile application exploits a one-way infrared connection (IrConn) to communicate with the haptic device. Sending a command is a trivial operation since it consists simply of writing bytes on the infrared port stream. As already mentioned, to execute a basic haptic message two commands must be sent: the first for starting and the second for ending the vibration. The application has to manage the haptic duration as well. While output complexity grows, i.e. many custom vibrating sequences are needed, a mechanism to organize and execute them is highly desirable. The development of such architectural framework was performed simultaneously with the creation of a tool for editing custom patterns through the PDA touchscreen (see Figure 3). The sequence of the vibrotactile output for each side (left/right) is defined by dragging the curve, which is associated with the vibration intensity over time. By choosing size and delay it is possible to define the pattern granularity.

The vibration intensity values can be stored in an XML file containing the delay value (which indicates the duration of each intensity value, which is the same for all of them) and two vectors of integers in the range [-1, 255] (where -1 means “motor off”).

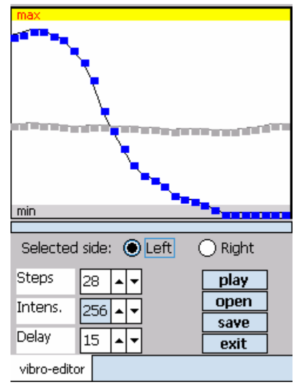

Figure 3. The environment for editing the vibrotactile patterns.

The higher layer of the HapticManager module (see Figure 4) exposes a method to load XML defined sequences into data structures (in memory). Loading may be performed during the application initialization.

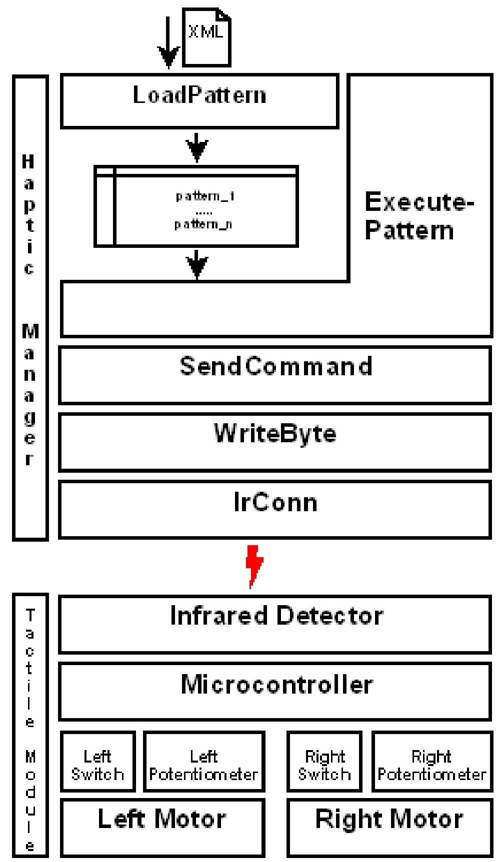

Figure 4. Hardware and software layers for the haptic framework.

Loaded sequences can be executed at run time by passing the related index to *ExecutePattern*. Execution consists on a cycle that reads data structures content and sends commands to the device. The cycle is performed by a thread with high priority to preserve the curve pitch. Since the XML file parsing is done only once, that is at loading time, the execution latency is minimized.

4. OBSTACLE AVOIDANCE SUPPORT

Obstacle detection is enabled by a Sharp-GP2D12 sensor embedded on the compass device. Obstacles are detected when they are between 10 and 90 cm from the user and within a cone of about 35°. Since the distance (as well as the orientation) is sampled at about 30 Hz, the upload latency is less than 40 ms. Thus, the mobile application is able to warn of approaching obstacles such as walls or other people.

While direction aids are given by left or right side haptic messages with intensity and duration depending on the turning angle, obstacle distance is provided by the same sequence on both sides. So far we have considered 3 levels of feedback each of which is related to a distance interval. The feedback strength is given by the duration and frequency of the impulses forming the sequence that increase as distance decrease.

We are planning to test two versions of the support: the one already described and another one that provides feedback only when the obstacle distance reduces (i.e. when the user moves towards it). Through the next test we will also ask users for their opinion about the vibration sequences.

Figure 5. A blind carrying the mobile guide in the left hand and the orientation/distance detector as a belt.

Figure 6. Detail of the compass device. The white cylinder on the top is the compass sensor; the distance sensor is located on the bottom-left.

5. USER TEST

The early investigation on vibrotactile feedback for orientation purposes [10], was dedicated to determining whether users preferred vocal sentences or haptic messages as orientation aids. Although no significant preference emerged, we opted to combine the vocal and haptic channels to indicate the direction to take because their combination seemed to provide more information. According to the observations made by some users we integrated obstacle detection into the system to signal obstacles in front of the user by means of haptic feedback. Custom sequences, with increasing vibration intensity when approaching any obstacle were produced on both fingers.

The latest user test was aimed to evaluate two versions of the above-mentioned obstacle detection: one with continuous vibration whose intensity depends on the obstacle distance, and the other providing vibration only when the distance to the obstacle decreases.

A group of 7 blind users, aged between 25 and 40, was involved. Three of them were women and 4 men.

Each user tested both versions of the obstacle avoidance feedback. Each of the two trials consisted of reaching a target artwork while coping with some obstacles in the environment. The two target artworks were different. All users wore the obstacle detection in a belt on their left hip, held the PDA in the left hand, and had the vibrating motors attached with Velcro on the same fingers (thumb and index), and started from the same location. However, in order to avoid any bias in the learning process, half of the users tried the continuous feedback version first and then the discontinuous, while the order was inverted for the others.

For each user, we logged the time taken to perform the requested tasks. The time spent serves as an index to compare the effectiveness of the two versions. All the users were able to perform the tasks and at the end of the test they were asked to compile a questionnaire with subjective considerations and possible suggestions. Each version of the haptic support was rated on a scale from 1 (the most negative value) to 5 (the most positive value).

According to the rating, (mean = 4.00 - 3.28, SD = 1.25 – 1.15), the version with discontinuous vibration was rated higher, though the difference was not statistically significant. Due to the small sample sizes ($n<10$) we applied non parametric tests [14].

The normality could not be verified due to the small sample size ($n<10$).

We used the exact Wilcoxon sign test to verify the differences in the time to perform the task (by the same users) and in the preference score expressed by each user for the two versions ($k=2$; $n=7$).

Users that preferred such support described it as less annoying than the continuous feedback, especially when standing in front of an artwork or an obstacle such as a wall. Since the Exact Wilcoxon test provided $p = 0.12$, we may not assert any trend. Probably this is due to the small of sample.

On the other hand, 4 of the 7 users preferred the continuous feedback, indicating a slight preference for such a support overall. This choice was motivated by the "safety" users felt with a continuous indication about an obstacle and is confirmed by the task duration: the mean times taken to reach the targets were 139 (SD=50.95) and 155 (SD=54.71) sec for the continuous and discontinuous vibrotactile feedback, respectively. The difference of time spent for performing the task by using the two versions is significant ($p<0.05$). Users spent les time to achieve the task by using the continuous vibrotactile prototype.

Additional observations were also collected: most users reported that the system latency in providing aids should be reduced. Other suggestions regarded possible improvements in the hardware positioning so as to not obstruct user's movements: the device line of sight when on the hip was sometimes obstructed by the users' arms.

6. CONCLUSION AND FUTURE WORK

We have presented a solution, which supports haptic feedback for user orientation and obstacle avoidance in a mobile guide for blind users.

In order to evaluate the new haptic modality introduced in our proposed prototype we have carried out a user test. Statistical analyses on the test results do not highlight trends towards a particular feedback mode. However, as users clearly motivated their preference (some found the continuous vibration annoying while others felt it as more "safe"), we plan to create a customizable haptic output to let the user choose the mode. We also plan to set up a context dependent mode, that is to signal obstacles on the path to the target (e.g. other people) through continuous vibration and switching to the discontinuous mode when the target is reached (the target item is, implicitly, an obstacle).

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