Extending Mobile User Ambient Awareness for Nomadic Text Entry

Ahmed Sabbir Arif
York University
Toronto, Ontario, Canada
asarif@cse.yorku.ca

Benedikt Iltisberger
Hochschule Bonn-Rhein-Sieg
Nordrhein-Westfalen, Germany
biltis@smail.inf.h-brs.de

Wolfgang Stuerzlinger
York University
Toronto, Ontario, Canada
wolfgang@cse.yorku.ca

ABSTRACT

Nowadays, we input text not only on stationary devices, but also on handheld devices while walking, driving, or commuting. Text entry on the move, which we term as *nomadic text entry*, is generally slower. This is partially due to the need for users to move their visual focus from the device to their surroundings for navigational purposes and back. To investigate if better feedback about users' surroundings on the device can improve performance, we present a number of new and existing feedback systems: *textual, visual, textual & visual,* and *textual & visual via translucent keyboard*. Experimental comparisons between the conventional and these techniques established that increased ambient awareness for mobile users enhances nomadic text entry performance. Results showed that the *textual* and the *textual & visual via translucent keyboard* conditions increased text entry speed by 14% and 11%, respectively, and reduced the error rate by 13% compared to the regular technique. The two methods also significantly reduced the number of collisions with obstacles.

Author Keywords

Mobile or handheld device, virtual or soft keyboard, text entry in motion, nomadic text entry, walking, driving, commuting, touchscreen.

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation (e.g., HCI): User Interfaces – Input devices and strategies.

INTRODUCTION

Handheld devices have become an integral part of our everyday life and text input has become ubiquitous. We input text not only on stationary devices such as desktop computers but also on handheld devices when we are in motion such as walking, driving, or commuting. We term the latter scenario as *nomadic text entry*. In nomadic text entry there is a natural competition for the users' attention between the device and the ambient environment.

Although, walking and typing can be performed simultaneously, perfect task parallelism is not possible as it involves a limited peripheral resource - our eyes (Meyer and Kieras, 1997). The need to move the eyes from one part of the visual field to the other requires a balance between the tasks, which precludes the possibility of perfect task parallelism. The corresponding division of attention depends mostly on environmental factors, such as other people, objects, noise, light, etc. Changes in any of these factors can force the user to swap priorities between tasks and compromise user comfort. For example, while walking on a crowded street, navigating through the crowd may take priority over mobile interaction. This division of attention interferes with users' ability to perform quickly and accurately in terms of text entry (Hillman *et al.*, 1999).

Numerous studies have been conducted to confirm this. Many examined the extension of awareness to improve the quality of collaborative work as well. However, not much work has been done on developing techniques to improve performance for nomadic text entry. In an attempt to counteract this, we present four environmental awareness methods in this paper: *textual*, *visual*, *textual & visual*, and *textual & visual via translucent keyboard*. The idea is to provide users with real-time feedback about their surroundings to increase their awareness of the environment. Our initial assumption is that this will improve nomadic text entry performance by reducing the competition for the users' focus between the device and the ambient environment.

We start this article by reviewing related work and then discuss the motivation behind our approach. Then, we introduce two new and two existing methods for providing feedback to mobile users and discuss design decisions. Next, we verify our claims by conducting a user study that compares text entry techniques augmented with environmental feedback with a conventional virtual keyboard and present the results. Finally, we end by speculating on future extensions and opportunities.

RELATED WORK

Researchers have investigated a number of issues in nomadic text entry. Brewster *et al.* (Brewster *et al.*, 2003) observed that users usually focus their visual attention on navigating the ambient environment while walking. This makes visually demanding interfaces hard to operate. To overcome this, they developed two new eyes-free multimodal gesture recognition techniques that allow users to select items with head and finger gestures. They tested their techniques with a belt-mounted PDA in both stationary and mobile settings, with and without auditory feedback. Results showed that user gestures were more accurate when dynamically guided by auditory feedback compared to no feedback. A similar study (Lumsden and Gammell, 2004) proposed a novel audio-enhanced unistroke-based text entry system for nomadic text entry. Similar to Brewster *et al.* (Brewster *et al.*, 2003), results

OZCHI 2011, Nov 28 – Dec 2, 2010, Canberra, Australia.

OZCHI 2011 Proceedings ISBN: 978-1-4503-1090-1

showed that users were more aware of their errors when they were dynamically guided by audio feedback.

In a recent study Marentakis and Brewster (Marentakis and Brewster, 2006) investigated the effect of feedback, mobility, and index of difficulty *ID* on a deictic spatial audio target acquisition task. Results confirmed that such tasks do abide by Fitts' law. However, no effect of audio feedback on users' workload or walking speed was found.

Lin *et al.* (Lin *et al.*, 2005) conducted a Fitts' law study of stylus tapping while walking. Results indicated that tapping performance decreased for smaller-sized targets while walking. A subsequent study (Lin *et al.*, 2007) confirmed that the subjective workload and overall task completion time of stylus tapping tasks increases while walking. Hence, they recommended that designers should use substantially larger buttons for interfaces that are to be used in nomadic settings compared to their immobile counterparts.

Mizobuchi *et al.* (Mizobuchi *et al.*, 2005) investigated the possibility of using walking speed during nomadic text entry as a secondary task measure for mental workload. For this, they studied nomadic text entry performance with different sized user interfaces on a PDA with a stylus. Their results showed that performance decreased while walking and also with smaller user interfaces.

Mustonen *et al.* (Mustonen *et al.*, 2004) examined the legibility of natural text, i.e. real text, and pseudo-text, i.e. random text, on a mobile phone while walking. They found that in both cases performance suffered from faster walking speeds. Barnard *et al.* (Barnard *et al.*, 2005) conducted a similar study where participants performed reading comprehension and text search tasks while seated and while walking on a treadmill. Interestingly, their results did not indicate any significant difference between the seated and the treadmill conditions in terms of task completion time. We hypothesize that the fixed ambient environment on the treadmill may have caused this.

MacKay *et al.* (MacKay *et al.*, 2005) compared different software navigation techniques on a PDA with a stylus while stationary and while mobile. Results showed that participants were significantly slower with all techniques while walking in a public area compared to while seated or standing. Chamberlain and Kalawsky (Chamberlain and Kalawsky, 2004) conducted a similar study to evaluate target selections with a stylus in a vest-based wearable computing system. They found an increase in selection time when participants were walking but did not find any significant difference in accuracy. Yatani and Truong (Yatani and Truong, 2007) designed a two-handed virtual chorded keyboard for PDA that uses both a stylus and the thumb of the non-dominant hand to input text. They compared their new technique with mini-Qwerty, handwriting, and Quikwriting in both stationary and mobile settings. Unlike Chamberlain and Kalawsky (Chamberlain and Kalawsky, 2004), results showed that mobility impacts text entry performance not only in terms of entry speed but also in accuracy and mental workload.

Hoggan *et al.* (Hoggan *et al.*, 2008) conducted a study to investigate if synthetic tactile feedback can improve the performance of mobile touchscreen text entry. Uses inputted text with three mobile keyboards: mini-Qwerty, conventional touchscreen, and touchscreen augmented with synthetic tactile feedback such as vibration, while walking and while riding underground trains. Results confirmed that the addition of synthetic tactile feedback significantly improved mobile touchscreen text entry.

A recent study (Crease *et al.*, 2007) proposed a novel evaluation technique that mimics a realistic mobile usage context in a lab setting. The technique used a straight path, which was created by placing coloured mats on the floor, as a basis for dynamically changing paths that the participants must follow. Dynamic paths were created by specifying different floor markings, i.e. mat colours, as hazards at different points in time, where users were not allowed to step on the hazardous markings while walking between two points. Three ceiling mounted projectors were used to project instructions on the hazards and onto the walls facing the participants. This technique, however, focused only on straight paths, whereas in real life users are expected to change directions. Moreover, projection equipment is required to utilize this method in text entry experiments, and this is not representative for a real-world task.

MOTIVATION

It is evident from the literature that nomadic text entry reduces performance. Although walking and text entry are largely separable tasks, there is a fixed cost for each task due to the presence of the secondary task. Numerous studies have confirmed the fact that as users walk, entry speed decreases while error rate and mental workload increases. Others unsuccessfully attempted to model this relationship. However, not much research has been directed towards solutions. In our work, we attempt to increase users' awareness of their ambient environment by providing them with real-time feedback on their surroundings. Our initial assumption is that this will improve nomadic text entry performance. We based our assumption on the fact that there is a natural competition for the users' attention between the task on the mobile device and the ambient environment (Meyer and Kieras, 1997). As discussed, although typing and walking are often performed simultaneously, perfect task parallelism is not possible in this dual-task as it involves the eyes, which is a limited peripheral resource. As a result, the necessity for moving the focus from one part of the visual field to the other does not only block the possibility of task parallelism but also interferes with the users' ability to perform quickly and accurately (Hillman *et al.*, 1999). Hence, reducing this competition for focus should allow users to perform better.

It is also necessary to understand how humans navigate through their ambient environment to develop a feedback system that will assist users with their navigation. It is commonly observed that users are mostly occupied with instant spatial factors, such as passers-by, street vendors, walkway blockades or obstacles, etc., while walking. A well-received hypothesis in psychology states that the human navigation system is fundamentally a dynamic, egocentric representation (Wang and Spelke, 2000;

Wang, 1999). According to this hypothesis, "*Humans navigate by establishing a set of target locations in the immediate environment and continuously computing the positions of these targets relative to themselves as they move, using various internal and external perceptual cues*" (Wang and Brockmole, 2003). Because this representation is egocentric, the location and the direction of all targets change constantly relative to the person as he/she walks. Therefore, if a feedback system is to provide information about the ambient environment, it is essential to make sure that the system can adjust and correct itself constantly based on all possible targets relative to the user. Such feedback systems may also assist users to improve their walking performance, such as increase average walking speed and reduce collision or misdirection, as they will be more informed about their surroundings. Here, we also investigate this.

FEEDBACK TECHNIQUES

Keeping the discussed arguments in mind, here, we present four feedback systems to assist nomadic text entry: *textual*, *visual*, *textual & visual*, and *textual & visual via translucent keyboard*. These feedback systems are capable of adjusting and correcting feedback as users change their perspective. Hence, they aim to assist with suitable information for navigation without the user having to frequently change visual focus. All of them aim to reduce the number of visual focus swaps by placing important elements close to the text entry area or to the keyboard. Users already swap their attention regularly between the text entry area and the keyboard frequently in text entry (Arif and Stuerzlinger, 2010).

Textual Feedback

The *textual* feedback method provides information in textual or written form. It can be compared with the text-based turn-by-turn directional information provided by currently available GPS navigation devices. However, as this feedback is exclusively text-based, it may often be necessary for the uses to visually verify the feedback provided by the system. Figure 1 (a) shows a text entry technique augmented with *textual* feedback. We place the *textual* feedback bar above the input text field.

During the experiment, we used the Wizard of Oz (WOz) method (Gould *et al.*, 1982) to provide *textual* feedback to the users as we consider implementing such a system outside the scope of the work reported here. However, we emphasize that GPS navigation devices already provide such turn-by-turn instructions in outdoor environments.

Visual Feedback

Visual feedback provides feedback with live video. In this method, the camera embedded in almost all modern mobile devices is used to show a view of the environment behind the device on the mobile screen. Theoretically and as the feedback is in visual form, this should further reduce the number of focus swaps. Figure 1 (b) illustrates our augmented text entry technique with visual feedback. Similar to the previous method, we place the projection area above the text input field.

Textual & Visual Feedback

This method combines *textual* and *visual* feedback together. Figure 1 (c) illustrated this technique. In this method, we again place the projection area above the text input field. We also display textual feedback in a translucent (alpha = 0.5) feedback bar that is placed at the bottom of the video area. We used a translucent bar to ensure that the dimension of the visual feedback area is not compromised.

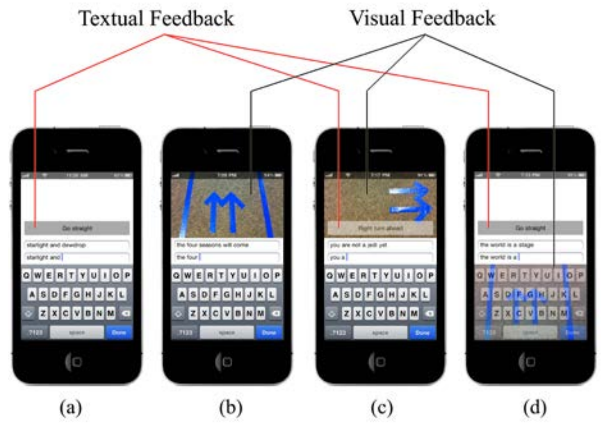

Figure 1. Text entry technique augmented with feedback in (a) textual, (b) visual, (c) textual & visual, and (d) textual & visual via translucent keyboard form.

Textual & Visual via Translucent Keyboard Feedback

Similar to *textual & visual* feedback this method provides feedback in both textual and visual form. However, instead of using a separate visual feedback area, this method uses a translucent virtual keyboard (alpha = 0.35) to show the camera view behind the keys. With the other three conditions users may need to swap their focus more frequently within the user interface as feedback is provided in a separate area of the interface. This method, on the contrary, attempts to eliminate this by providing visual feedback directly on the keyboard. Figure 1 (d) illustrates it.

Figure 2. Recent commercial applications providing visual feedback via translucent virtual keyboard and/or text area: (a) Road SMS, (b) Type n Walk, and (c) Walk and Text.

Similar Feedback Methods

We found three recent mobile touchscreen applications that utilize a similar strategy to assist nomadic text entry, see Figure 2. Two applications from the Android Market[1], *Road SMS* and *Walk and Text*, use the built-in camera to show the view on a translucent application for texting. An Apple iPhone application, called *Type n Walk*[2], shows the camera view behind the text input area. However, there is no empirical study available on the performance and usability of these techniques.

---

[1] http://market.android.com

[2] http://www.type-n-walk.com

Besides, these applications show the camera view either on the whole screen with keys arranged across that whole screen or show the camera video behind the text input area. We decided against this design based on the results of a pilot. A number of participants from that pilot complained that it was hard for them to recognize the keys and to verify the inputted text when the background colour matched the key and/or the font colour. They also found it hard to focus on the task of text entry as the background kept changing. Therefore, we made the keyboard background only partially translucent instead of fully transparent and kept the text input area solid for all techniques.

Additional Combinations

Here, we propose two combined feedback systems: one that combines *textual* and *visual* feedback and the other combining *textual* and *visual via translucent keyboard*. Although, it is possible to combine *visual* and *visual via translucent keyboard* and also *textual*, *visual*, and *visual via translucent keyboard*, we decided against these two combinations in our user study. The reason is that these methods will occupy almost the whole display screen, with which users do not seem to feel comfortable. As discussed, several users complained during the pilot study that it is hard for them to concentrate on text entry when the display screen changed constantly. The latter technique also includes *textual* feedback. This adds additional complexity to the task as not only the screen keeps changing but also the users are forced to swap their focus between multiple regions of the device, such as the upper and the lower projection areas, the textual feedback bar, and the text input field. Besides and as discussed, the text input field must be solid, as matching background colours make it (almost) impossible for the users to verify the inputted text. Using a solid text input field avoids this.

Reliability of the Textual Feedback

As discussed, the *textual* feedback can be compared with turn-by-turn directional information provided by GPS navigation devices that are used in automobiles or for hiking. These devices keep the user informed about the best route to their destination via directional information. This information is provided in both textual and verbal form, and then displayed on the screen. This could easily be adapted to provide users only with *textual* feedback. The turn-by-turn directional information is usually high-level. It cannot warn pedestrians of a possible collision with an incoming passer-by. Therefore, it is not always useful in isolation. Technological advances, however, promise better navigation systems in near future. A recent survey (Zickuhr, 2011) showed that 85% of American adults own a handheld device, a large number of which include GPS navigation. It may be possible to develop a wireless system that uses information about other nearby GPS units to detect passers-by on a potential collision course. However, for this to work significant advances in GPS accuracy are necessary. Many pattern recognition methods have also been proposed in recent years for the abstraction of video (Antania, 2002). Such methods could be used to analyze the output of the device's embedded camera to identify and warn users about a potential hazard, such as an open manhole or a puddle. However, the system not only has to be able to recognize objects around the users but also has to make decisions on what information to display to them. This requires a high level of recognition accuracy and an understanding of the surrounding. We also recognize that the system has to be reasonably reliable to be useful. However, this is a problem outside the scope of this work.

Projected View

We observed that users usually hold their devices in 10–40° angles while inputting text, see Figure 6. This allows *visual* and *visual via translucent keyboard* to show the next few metres of the path as seen by the embedded camera at any given point, including obstacles and the feet of nearby passers-by, see Figure 1 (b). This is highly beneficial in this context, as this is the most important information for short-term navigation. While holding the device in a more vertical position will cover a much wider view, this will exclude the immediate next few meters of the path and thus contains information that does not require immediate attention and thus has to be explicitly remembered, which is not desirable.

Seizing User Attention vs. Other Methods

Our methods attempt to keep the users' visual focus on the device during nomadic text entry instead of completely removing the need for constant attention to the device. This is motivated by the fact that prior studies that investigated alternate methods that do not require constantly looking at the device were unable to establish their superiority over the conventional technique.

Brewster *et al.* (Brewster *et al.*, 2003) argued that speech recognition is not a realistic choice for nomadic text entry. First, these techniques are usually error prone and even to acquire an acceptable accuracy rate require a large dataset. This makes these techniques heavyweight and usually impractical to use with mobile devices. Also, recognition rate drops drastically when used in noisy environments. Various gesture (Brewster *et al.*, 2003) and handwriting (Lumsden and Gammell, 2004) techniques were also examined for nomadic text entry. Results showed that these methods are beneficial only when dynamically guided by auditory feedback. In other words, if the user is unable to listen to the auditory feedback, for example in a noisy environment, the performance of these techniques will decrease. Mankoff and Abowd (Mankoff and Abowd, 1999) pointed out that voice- and gesture-based techniques frequently use alternate modalities, such as manual input, handwriting, etc., for error correction. This adds further complexity to these techniques, especially for mobile scenarios. Hence, we take a straightforward approach to reduce the cognitive and motoric load by decreasing the need for both visual focus and modal swaps.

The keys on mobile keyboards, either physical or virtual, are relatively small. Hence, a whole fingertip usually covers a key completely while typing. This makes it somewhat harder for users to visually find and press the right key. However, with physical keyboards users can feel the keys under their fingers and experience an opposite force when pressing the keys. This feedback helps experienced users to locate keys, sometimes even when they are not looking at the device. Virtual keyboards, in contrast, are deprived of this feedback. Hence, there is a greater need for the users to swap their visual focus while typing with a virtual keyboard compared to a physical one. Therefore, it is plausible that better feedback methods will benefit virtual keyboards more. However, we believe that physical keyboards will also benefit from these methods as it is not possible to avoid looking at the device completely. Previous studies (Salthouse, 1986) showed that users have the tendency of constantly verifying their input and in order to do so one has to look at the device. Moreover, numerous mobile applications require constant visual attention regardless of the type of keyboard. For example, text messaging or online chatting applications demand almost constant visual focus of the user as they have to read the incoming messages before replying to them.

AN EXPERIMENT

Apparatus

We used an Apple iPhone 4, 58.6×115.2×9.3 mm and 137 grams, at 960×640 pixel resolution with 326 ppi for our experiment. A custom application, developed with the iPhone SDK, was used during the study. The application used a conventional touchscreen soft keyboard, similar to the iPhone's default, during the study. See Figure 3. The application logged all interactions with timestamps and calculated user performance directly.

We used the iPhone's wireless connection to buffer and synchronize all data with a database through a web service. The application was programmed to reconnect and start buffering immediately in case of a connection loss. For the same reason, all data was stored locally on the device. However, connection loss did not occur during the experiment. We used an Ajax-based custom web application to display the incoming data in a web browser in real-time. To simulate the *textual* feedback, an experimenter on a laptop served as the "Wizard of Oz" and used this web application to send textual information directly to the iPhone.

Figure 3. The device, Apple iPhone 4, and the Qwerty keyboard layout used during the user study.

Participants

Twelve participants from the university community took part in the experiment. They were selected randomly, aged from 18 to 25 years, average 22. Five of them were female and one of them was a left-hand mouse user. All participants were proficient in the English language. They were either native speakers or had spent at least five years in the same or similar English speaking environment. All of them were familiar with the Qwerty layout and two of them were touch typists. Eleven of the participants had prior experience with touchscreens and seven of them owned a touchscreen-based handheld device. All of them were frequent mobile phone users that, on average, use their devices for more than two hours a day and send 248 text messages per week. They received a small compensation for their participation.

Procedure

Participants entered short English phrases from a widely used phrase set (MacKenzie and Soukoreff, 2003) during the user study. This corpus was chosen due to its high correlation with the character frequency in the English language. Besides, these phrases are widely used in recent text entry studies and contain only characters and spaces. Phrases from the set were shown in random order to the participants on the display, all in lowercase. Participants held the device in the portrait position and typed using both of their thumbs. See Figure 6. They were asked to take the time to read and understand the phrases in advance, then to enter them as fast and accurate as possible, and to press the "Done" key when they were finished with one phrase to see the next. Participants were provided with two practice phrases before each condition to make sure that they were moderately familiar with the techniques and the protocol. They could extend this practice on request. Timing started from the entry of the first character and ended with the last. Participants were informed that they could rest between sessions. They were also asked to work normally, that is, to correct their errors as they noticed them. However, they had to exclusively use the "Backspace" button for editing as we disabled direct cursor control in order to remove a potential confounding factor.

The experiment took place in an empty room, sized approximately 7.5×6 metres. A lighting level of about 400 lux was maintained during the study by keeping the room lights at full illumination.

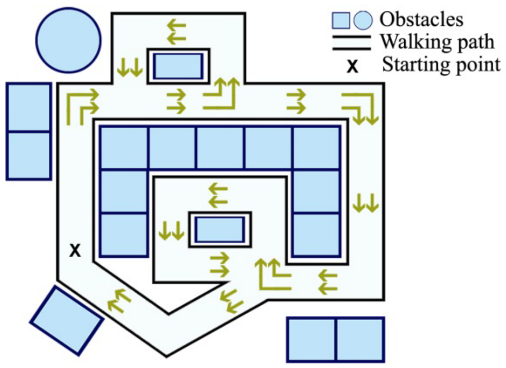

Figure 4. Diagram of the obstacle course path used to construct the attention-intensive walking condition. The room dimensions were approximately 7.5x6 metres.

We used the commonly used WPM metric to measure text entry speed (Arif and Sturzlinger, 2009). For error rates we used Soukoreff and MacKenzie's Total ER metric (Soukoreff and MacKenzie, 2003). This metric gives better insight into the behaviours of users, as it unifies the effect of accuracy during and after text entry. This metric measures the ratio of the total number of incorrect and corrected characters, in relation to the total number of correct, incorrect, and corrected characters. We also calculated the cost of error correction T_{fix} (Arif and Stuerzlinger, 2010, which predicts the extra time a technique requires on average per character to fix errors.

At first, we measured a participant's stationary typing performance. For this, each participant was asked to input fifteen random phrases in a seated position, see Figure 6 (a). Participants were then asked to walk without texting through an obstacle course path, to measure their normal walking speed. An obstacle course path mimics realistic walking environments by forcing users' attention to the obstacles placed along the path. We designed our path to approximate Barnard *et al.*'s path (Barnard *et al.*, 2005), as it has been used in other studies. This allows for more effective comparisons between results (Lin *et al.*, 2005). A diagram of the path is shown in Figure 4. The path was approximately 24 metres long. All elements of the diagram are roughly to scale, except for the width of the tape and the indication signs that have been amplified for visual clarity. In practice, we taped a 1.6 feet wide path to the floor with indication signs to navigate participants through the path in a globally clockwise direction. The course direction was kept uniform for all sessions. Light furniture and cardboard boxes were used as obstacles to minimize potential physical hazards, see Figure 5. A trained first aider was present at all times during the proceedings to treat injuries in case of minor accidents. However, such incidents did not occur during the study.

Participants were asked to take two laps through the path from the starting point. They were instructed to walk normally. They were also instructed to strictly follow the signs and to avoid hitting the obstacles. A second experimenter manually recorded the lap times and the total number of wrong turns and bumps using an electronic stopwatch and a spreadsheet.

Figure 5. The wizard and a partial view of the experiment space.

Subsequently, we started our main experiment on nomadic text entry techniques. Participants were asked to walk through the course path while inputting text with five techniques: a conventional touchscreen keyboard and the above mentioned four keyboards augmented with various forms of feedback. Participants were given the same instructions as for other text entry studies. That is, to type as fast and as accurate as possible and to correct errors as they noticed them. They were also instructed to follow the signs strictly and to avoid hitting obstacles as they walk. There was one session per technique, five sessions in total. Participants inputted fifteen phrases in each session and started walking from the starting point, see Figure 4. They kept walking along the indicated path until they completed the session. The virtual keyboard disappeared after the last phrase was entered, indicating the completion of a session. Participants were instructed to immediately stop walking after they were done.

The record-keeper kept a manual record of the total number of laps, wrong turns, and bumps in a spreadsheet. A lap was recorded when users walked round the path (roughly 24 metres) a single time. Lap time is the time it takes for a user to complete one lap. The obstacle path contained thirteen turns, including three intersections. Hence, theoretically it was possible for the users to take a wrong turn in thirteen different occasions. However, we observed that participants are most likely to take a wrong turn while on an intersection. Each time a user went in a wrong direction a wrong turn was recorded. However, all users realized almost immediately that they made a mistake and corrected their course. When users collided with an obstacle, a bump was recorded.

(a) (b)

Figure 6. A participant inputting text while: (a) stationary, i.e. in a seated position, and (b) mobile, i.e. walking.

We used the Wizard of Oz (WOz) method to provide *textual* feedback to mobile users. Two experimenters were present during the study at all times. The first experimenter kept a manual record of all events that could not be recorded directly by the systems. The second experimenter played the part of the wizard. He carefully observed the participants as they walked, and sent appropriate *textual* feedback directly to their iPhone in the appropriate situations. The wizard used a custom Ajax-based web application on a laptop computer to pick the currently appropriate feedback from a pre-set list containing messages such as "go straight", "left turn ahead", and then to transmit that message to the device. The same set and number of feedback was sent to each participant. The wizard had to be consistently alert to be able to provide useful feedback to the users. As everyone has a different walking speed and style, it was necessary for the wizard to observe participants closely while walking, to estimate the right time-interval for each scenario to send feedback to them. For example, while it might be too late to warn a fast-walking user two seconds before a probable collision, the same time may be too early for a slow-walking one. To account for the possibility of mistakes by the wizard, the record-keeper also recorded the wizard's mistakes – when wrong feedback was sent to the participant. Participants were not made aware of the fact that it was actually one of the experimenters who sent them *textual* feedback. Instead, they were told that the experimenters were there to record their typing and walking performance. They were given the impression that the system was capable of detecting obstacles autonomously to provide them with appropriate feedback. Finally, and after completion of all conditions, participants were asked to fill a short questionnaire where they could rate the different techniques on a five-point Likert scale and comment on them.

Design

We used a within-subject design for the five techniques. There were five sessions and in each session participants entered fifteen phrases with a different technique. Participants were randomly assigned into groups according to a Latin Square in order to avoid asymmetric skill transfer. In summary, the design was:

12 participants * 5 techniques * 15 phrases = 900 phrases, in total, excluding practice phrases.

RESULTS

During the experiment the wizard was able to maintain an accuracy of 99% in terms of correct and timely feedback. Thus, we are confident that our results are reasonably unbiased in this respect and generalizable to other implementations of our feedback methods.

Entry Speed

An ANOVA on the data indicated that there was a significant effect of feedback on nomadic text entry speed ($F_{4,11} = 3.33$, $p < .05$) for all mobile conditions. A Tukey-Kramer test revealed that techniques augmented with *textual* and *textual & visual via translucent keyboard* were significantly faster than the others. Figure 7 illustrates the average WPM and standard errors for the stationary condition and all nomadic techniques. Note that the average stationary text entry rate is only shown for reference.

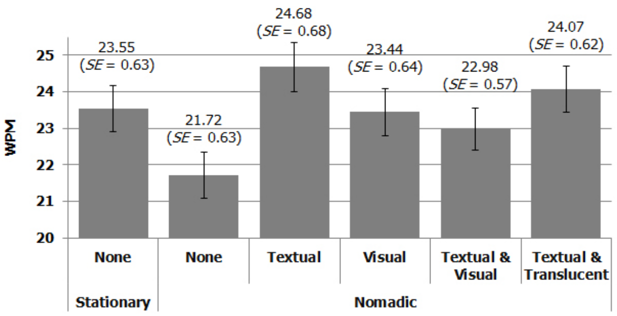

Figure 7. Average WPM with standard error (SE) for the stationary condition and all nomadic techniques. Note the scale on the vertical axis.

Error Rate

An ANOVA of the experiment data indicated that there was no significant effect of feedback on nomadic text entry error rate ($F_{4,11} = 0.76$, ns) across all nomadic conditions. Figure 8 shows the average Total ER for the stationary condition and all nomadic techniques. The average stationary text entry rate is shown for reference.

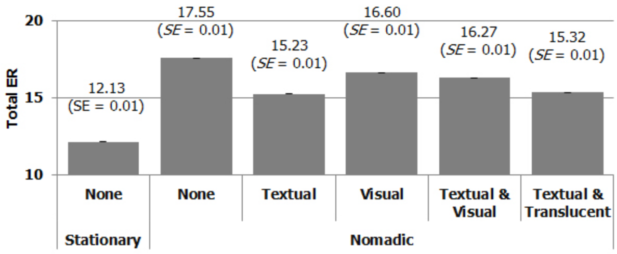

Figure 8. Average Total ER with standard error (SE) for the stationary condition and all nomadic techniques. Note the scale on the vertical axis.

The Cost of Error Correction

An ANOVA indicated that there was no significant effect of feedback on the cost of error correction ($F_{4,11} = 0.76$, ns) across all nomadic conditions. Figure 9 illustrates the average T_{fix} for the stationary condition and for all nomadic techniques. The average stationary text entry rate is shown for reference.

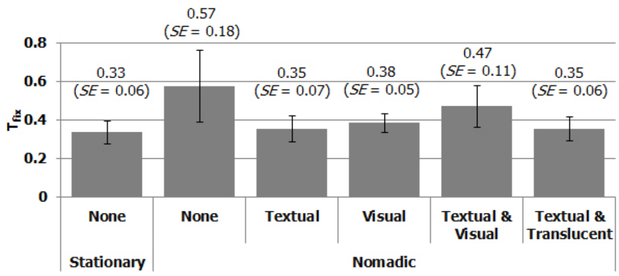

Figure 9. Average T_{fix} with standard error (SE) for the stationary condition and all nomadic techniques.

Walking Speed

An ANOVA on the data revealed that there was no significant effect of feedback systems on walking speed ($F_{4,11} = 1.04$, $p > .05$) across nomadic conditions. Figure 10 illustrates the average time to finish a lap for the normal walking condition and all nomadic text entry techniques. The normal walking speed is shown for reference.

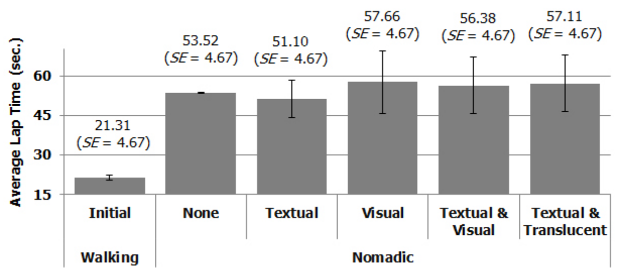

Figure 10. Average lap completion time with standard error. Note the scale on the vertical axis.

Wrong Turns

A Kruskal-Wallis One-Way ANOVA on the data showed significance with respect to the number of wrong turns ($H_4 = 10.00$, $p < .05$). Figure 11 illustrates the average percentage of wrong turns relative to the total number of laps finished with each technique during the experiment. Note that wrong turns were roughly distributed among participants. The number of wrong turns during normal walking is shown for reference.

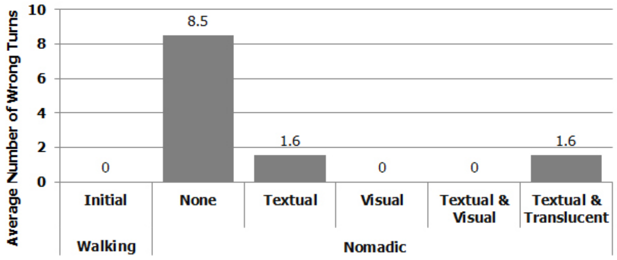

Figure 11. Average percentage of wrong turns relative to the number of laps finished.

Collisions

A Kruskal-Wallis One-Way ANOVA on the data did not indicate significance regarding the number of collisions ($H_4 = 3.93$, $p > .05$). Figure 12 illustrates the average percentage of the number of collisions relative to the total number of lap finished during all conditions.

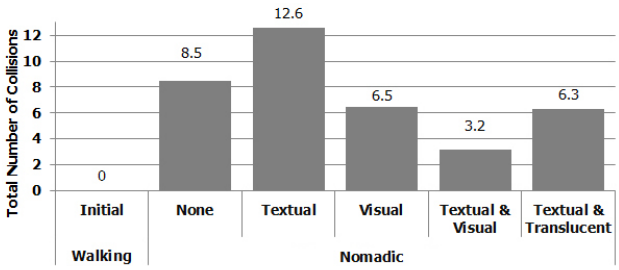

Figure 12. Average percentage of number of collisions relative to the number of laps finished.

User Feedback

A Kruskal-Wallis One-Way ANOVA on user feedback did not indicate significance with respect to user preference across techniques ($H_4 = 4.18$, $p > .05$). Figure 13 represents the average user ratings of the techniques on a five-point Likert scale.

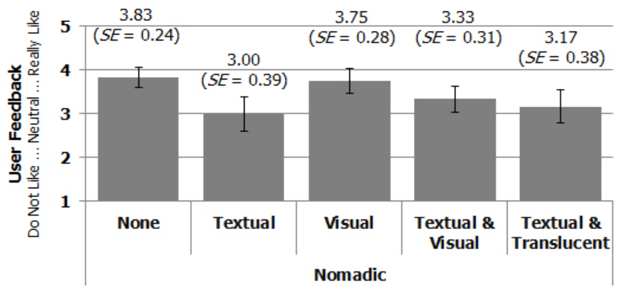

Figure 13. Average user feedback on a scale of 5. Here, 1 represents "do not like", 3 "neutral", and 5 "really like".

DISCUSSION

Text Entry Speed

Our initial assumption was that techniques augmented with the new forms of feedback would significantly improve nomadic text entry speed. The experimental results verify this assumption. *Textual*, *visual*, *textual & visual*, and *textual & visual via translucent keyboard* increased nomadic text entry speed by 14%, 8%, 6%, and 11% compared to the conventional technique, correspondingly. Further analysis revealed that *textual* and *textual & visual via translucent keyboard* were significantly faster than all other methods. Surprisingly, these two methods also yielded faster nomadic text entry speed compared to the stationary condition, even though this difference is likely not significant. One potential reason for this is that stationary text entry was measured prior to the original study, which kept it isolated from the effects of training and potential skill transfers.

Error Rate and the Cost of Error Correction

The results indicated that nomadic text entry was more error prone compared to the stationary condition and there was no significant effect of feedback on error rate. In other words, feedback did not reduce nomadic text entry error rates in a significant manner. On average, the error rate increased by 45% across all nomadic conditions compared to stationary text entry. Although an ANOVA on the data did not yield significance, techniques augmented with *textual*, *visual*, *textual & visual*, and *textual & visual via translucent keyboard* reduced error rates by 13%, 5%, 7%, and 13% compared to the conventional technique, respectively. The cost of error correction also increased during nomadic text entry. On average, the cost of error correction increased by 73% while walking and typing with the conventional technique. However, techniques augmented with *textual*, *visual*, *textual & visual*, and *textual & visual via translucent keyboard* reduced the cost of error correction by 39%, 33%, 18%, and 39% compared to the conventional technique, respectively. However, none of these improvements are significant.

Walking Speed

Participants took on average 159% more time to finish a lap during the nomadic conditions compared to the conventional technique. Walking speed remained almost constant across all nomadic conditions. We speculate that based on our instructions to participants typing took preference over walking, making typing the primary task and walking secondary. Hence, their primary motivation became to type faster and more accurate rather than to walk faster.

Wrong Turns and Collisions

Participants did not take any wrong turns during their non-text entry laps. In total, they took six wrong turns while inputting text with the conventional technique while walking, despite the markings on the floor. In conditions augmented with *textual*, *visual*, *textual & visual*, and *textual & visual via translucent keyboard*, the number of wrong turns reduced by 83%, 100%, 100%, and 83% compared to the conventional technique, respectively. There was, however, no significant change with respect to collisions across all nomadic techniques. On average, participants bumped into obstacles 5 times per technique for the nomadic conditions.

Overall Performance

Techniques augmented with *textual* and *textual & visual via translucent keyboard* had better overall performance compared to the other methods. *Textual* and *textual & visual via translucent keyboard* improved entry speed of nomadic text entry by 14% and 11%, respectively, and both reduced error rates by 13%, compared to the conventional technique. The cost of error correction also improved with these methods by 39% compared to the conventional technique. Walking speed was the fastest with *textual* feedback, 51.10 seconds per lap. However, the collision count was the highest with this method, for a total of 8 collisions. *Textual & visual via translucent keyboard*, on the other hand, had the highest lap time, 57.11 seconds per lap, and the second lowest collision count, 4 in total. Hence, it can be said that *textual* and *textual & visual via translucent keyboard* yielded the best overall performance.

User Feedback

Participant feedback did not yield information about notable differences between the nomadic techniques. Most participants felt "neutral" about the performance of the various forms of feedback. However, almost all of them agreed that the feedback systems may be valuable in a challenging environment such as in a crowded street or while walking on a street that is unknown to them. Many of them expressed their interest on acquiring a feedback system, if available. They were particularly interested in the technology used behind the textual feedback (we used a WOz method) and enquired if they could download or purchase a similar system.

CONCLUSION

We presented four feedback methods to extend ambient awareness to mobile users: *textual*, *visual*, *textual & visual*, and *textual & visual via translucent keyboard*. We conducted a user study to evaluate these methods. Results showed that the feedback systems improved the overall nomadic text entry performance in a significant manner and reduced the possibility of collisions.

Future Work

We used a static obstacle path for our study as mimicking dynamic paths in a lab setting is hard and requires special equipment. The disadvantage of using a static path is that sometimes if the path is not complex enough users quickly create a mental model of the path, which makes walking through the path a repeated task. To avoid this drawback we used an obstacle path similar to one widely used in the literature that ensures that the path is complex enough for the users to get used to with it in a short time. We also witnessed this during the experiment, as participants were constantly paid attention to the path and the feedback while walking and typing. However, in the future we plan to examine our techniques with a dynamic obstacle path as well. Also, we are looking at other forms of nomadic text entry, i.e. while driving or commuting.

A Longitudinal Study

Our results established that providing users with feedback enhances the overall nomadic text entry performance, but the improvement is not enormous. Some other mobile text input experiments conducted a longitudinal exploration of user performance. Hence, the question might arise if a longitudinal study would yield more sound conclusions? Training novice users to expertise does reduce the chance of biasing the data due to a user's lack of familiarity with the input device or interaction technique. However, we screened participants in our study so that the results were likely not influenced by different expertise levels. Also, if a short-term study indicates statistically different measures, the motivation for a longitudinal study is much reduced. Hence, we believe that a longitudinal evaluation may further strengthen the finding of this research but do not expect radically different insights.

ACKNOWLEDGMENTS

We would like to express our gratitude to Susan Cameron, Clara Masaro, and Penny O'Connor for their kind support and help. We also thank NSERC, OGSST, and York University for financial support.

REFERENCES

Antania, S., Kasturi, R., and Jain, R. A survey on the use of pattern recognition methods for abstraction, indexing and retrieval of images and video. Pattern Recognition 35, 4 (2002), 945-965.

Arif, A. S. and Stuerzlinger, W. Analysis of text entry performance metrics. In Proc. TIC-STH 2009, IEEE Press (2009), 100-105.

Arif, A. S. and Stuerzlinger, W. Predicting the cost of error correction in character-based text entry technologies. In Proc. CHI 2010, ACM Press (2010), 5-14.

Barnard, L., Yi, J. S., Jacko, J. A., and Sears, A. An empirical comparison of use-in-motion evaluation scenarios for mobile computing devices. Int. J. Hum.-Comput. Stud. 62, 4 (2005), 487-520.

Brewster, S., Lumsden, J., Bell, M., Hall, M., and Tasker, S. Multimodal 'eyes-free' interaction techniques for wearable devices. In Proc. CHI 2003, ACM Press (2003), 473-480.

Chamberlain, A. and Kalawsky, R. A comparative investigation into two pointing systems for use with wearable computers while mobile. In Proc. ISWC 2004, IEEE Press (2004), 110-117.

Crease, M., Lumsden, J., and Longworth, B. A technique for incorporating dynamic paths in lab-based mobile evaluations. In Proc. BCS-HCI 2007, British Computer Society (2007), 99-108.

Gould, J. D., Conti, J. and Hovanyecz, T. Composing letters with a simulated listening typewriter. In Proc. CHI 1982, ACM Press (1982), 367-370.

Hillman, E. J., Bloomberg, J. J., McDonald, P. V., and Cohen, H. S. Dynamic visual acuity while walking in normals and labyrinthine-deficient patients. Journal of Vestibular Research 9, 1 (1999), 49-57.

Hoggan, E., Brewster, S. A., and Johnston, J. Investigating the effectiveness of tactile feedback for mobile touchscreens. In Proc. CHI 2008, ACM Press (2008), 1573-1582.

Lin, M., Goldman, R., Price, K. J., Sears, A., and Jacko, J. How do people tap when walking? An empirical investigation of nomadic data entry. Int. J. Hum.-Comput. Stud. 65, 9 (2007), 759-769.

Lin, M., Price, K. J., Goldman, R., Sears, A., and Jacko, J. Tapping on the move - Fitts' law under mobile conditions. In Proc. IRMA 2005, Idea Group Publishing (2005), 132-135.

Lumsden, J. and Gammell, A. Mobile note taking: Investigating the efficacy of mobile text entry. In Proc. MobileHCI 2004, ACM Press (2004), 156-167.

MacKay, B., Dearman, D., Inkpen, K., and Watters, C. Walk 'n scroll: a comparison of software-based navigation techniques for different levels of mobility. In Proc. MobileHCI 2005, ACM Press (2005), 183-190.

MacKenzie, I. S. and Soukoreff, R. W. Phrase sets for evaluating text entry techniques. Ext. Abstracts CHI 2003, ACM Press (2003), 754-755.

Mankoff, J. and Abowd, G. D. Error correction techniques for handwriting, speech, and other ambiguous or error prone systems. Technical Report, Georgia Institute of Technology, Atlanta, GA (1999), GIT-GVU-99-18.

Marentakis, G. N. and Brewster, S. A. Effects of feedback, mobility and index of difficulty on deictic spatial audio target acquisition in the horizontal plane. In Proc. CHI 2006, ACM Press (2006), 359-368.

Meyer, D. E. and Kieras, D. E. A computational theory of executive cognitive processes and multiple-task performance: part 1. Basic mechanisms. Psychological Review 104, 1 (1997), 3-65.

Mizobuchi, S., Chignell, M., and Newton, D. Mobile text entry: relationship between walking speed and text input task difficulty. In Proc. MobileHCI 2005, ACM Press (2005), 122-128.

Mustonen, T., Olkkonen, M., and Hakkinen, J. Examining mobile phone text legibility while walking. Ext. Abstracts CHI 2004, ACM Press (2004), 1243-1246.

Salthouse, T. A. Perceptual, cognitive, and motoric aspects of transcription typing. Psychological Bulletin 99, 3 (1986), 303-319.

Soukoreff, R. W. and MacKenzie, I. S. Metrics for text entry research: an evaluation of MSD and KSPC, and a new unified error metric. In Proc. CHI 2003, ACM Press (2003), 113-120.

Wang, R. F. and Brockmole, J. R. Human navigation in nested environments. J Exp Psychol Learn Mem Cogn 29, 3 (2003), 398-404.

Wang, R. F. and Spelke, E. S. Updating egocentric representations in human navigation. Cognition 77, 3 (2000), 215-250.

Wang, R. F. Representing a stable environment by egocentric updating and invariant representations. Spatial Cognition & Computation 1, 4 (1999), 431-455.

Yatani, K. and Truong, K. N. An evaluation of stylus-based text entry methods on handheld devices in stationary and mobile settings. In Proc. MobileHCI 2007, ACM Press (2007), 487-494.

Zickuhr, K. Generations and their gadgets. Technical Report, Pew Research Center, Washington, DC (2011). http://pewinternet.org/Reports/2011/Generations-and-gadgets.aspx.