Touch & Interact: Touch-based Interaction of Mobile Phones with Displays

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ABSTRACT
The limited screen size and resolution of current mobile devices can still be problematic for map, multimedia and browsing applications. In this paper we present Touch & Interact: an interaction technique in which a mobile phone is able to touch a display, at any position, to perform selections. Through the combination of the output capabilities of the mobile phone and display, applications can share the entire display space. Moreover, there is potential to realize new interaction techniques between the phone and display. For example, select & pick and select & drop are interactions whereby entities can be picked up onto the phone or dropped onto the display. We report the implementation of Touch & Interact, its usage for a tourist guide application and experimental comparison. The latter shows that the performance of Touch & Interact is comparable to approaches based on a touch screen; it also shows the advantages of our system regarding ease of use, intuitiveness and enjoyment.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Input devices and strategies; Prototyping.*

General Terms
Measurement, Design, Experimentation, Human Factors.

Keywords
Touch & Interact, mobile interaction, dynamic display.

1. INTRODUCTION
The input and output capabilities of mobile phones are still far away from the simplicity and speed of conventional laptops or PC's. Unfortunately, a key limitation of these devices is the user's inability to view and interact with a large amount of information at once due to their limited visual output capabilities [1]. On the other hand, we have seen a remarkable improvement in large screen displays in the last few years, particularly: increased size, higher resolution and falling prices. Because of this, such displays can be seen more and more in office environments, airports, train stations, subways and homes. Therefore, the usage of mobile devices which interact with these public screens to overcome their limited visual output capabilities is seen as a promising future application area [2, 3, 4, 5]. Many direct and indirect mobile interaction techniques have been developed and tested which support interaction with passive (e.g. a paper map or newspaper) and dynamic displays (e.g. public screen or remote PC) [6]. But till now, no research has been reported in which a mobile phone was used to touch a display in order to pair these two devices and to perform selections on the display by touching corresponding locations.

This paper presents Touch & Interact, a direct manipulation interface for touch-based mobile interaction with dynamic displays. Touch & Interact can be used in conjunction with various displays. For example, the mobile device could be used as a first-class device for interaction with public screens, laptop screens, picture boards, electronic paper or shopping windows. A familiar example of direct interaction is the usage of a stylus when interacting with a PDA. In our system, a mobile device replaces the stylus and the PDA is replaced by a dynamic display. Using the presented interaction technique, the mobile device can be used to touch the dynamic display at any position in order to establish a pairing between these two devices and to perform a selection. The system tracks the interactions of the users and sends the corresponding events to the application logic. Based on these events, the information presented by the display and the mobile device is updated.

This paper discusses a realisation of this interaction technique, implemented using a grid of NFC/RFID tags and a NFC (Near Field Communication) phone. This implementation was then used to evaluate Touch & Interact based on two prototypes and for the implementation of a tourist information application.

A combination of conventional touch screen and mobile phone and a conventional display, controlled remotely with a mobile phone, are alternative solutions that can be used to overcome the limited visual output capabilities of mobile phones. We conducted a comparative study in order to compare these two alternatives with Touch & Interact. The results show that pointing and selection time of Touch & Interact is comparable to an alternative interaction based on a touch screen and is much faster than the alternative in which the mobile phone is used to control a mouse pointer remotely. Using a further prototype - a digital picture board, we compared Touch & Interact once more with a combination of a touch screen and a mobile phone. The results show no significant time difference between these two systems, but the outcome of an additional survey show that Touch & Interact has better results regarding ease of use, intuitiveness and enjoyment. In addition to the comparative study, this paper presents a tourist information prototype which shows how Touch & Interact can be used in a practical application.

The results of our studies provide strong evidence that Touch & Interact has a comparable performance to existing approaches,

MobileHCI 2008, September 2–5, 2008, Amsterdam, the Netherlands.

and that potential users see ease of use, intuitiveness and enjoyment as advantages of this interaction technique.

2. INTERACTION TECHNIQUE

Using Touch & Interact, a person is able to touch a corresponding screen with their mobile device in order to perform interactions. The approach is comparable to a touch screen but the mobile phone replaces the finger during interaction. Consequently, the mobile phone can be utilized throughout the interaction offering: an auxiliary display, audio and haptic feedback, storage capabilities and connectivity for Internet access.

2.1 Interactions

As the mobile phone can be used as a generic pointing device, it is possible to reuse almost all interactions we know from standard WIMP interfaces. Supplementary to the interactions is the combination of the input and output capabilities, provided by the dynamic screen and mobile phone. The potential for useful interactions is based on the interplay of these two capabilities. Figure 1 shows an example interaction with a button displayed by the dynamic screen. During interaction, both devices provide corresponding feedback.

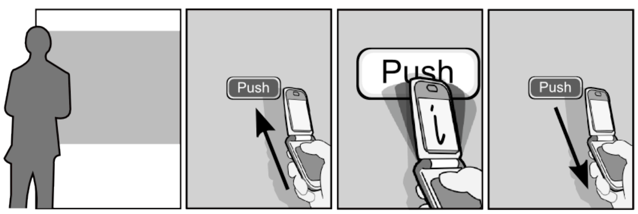


Figure 1. Button interaction sequence using Touch & Interact.

Figure 2 illustrates the implementation of select & pick using Touch & Interact. In this example, the user interacts with a picture board by touching the picture with the phone and in response, the picture moves from the dynamic display to the phone. This interaction technique is very intuitive and corresponds to experiences one gathers when interacting with physical objects.

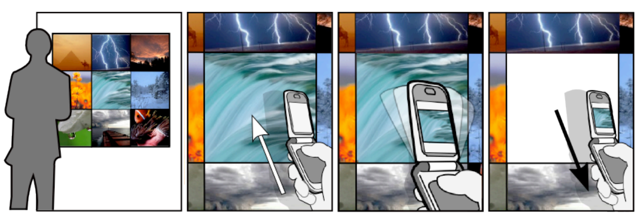


Figure 2. Select & pick using Touch & Interact.

Figure 3 illustrates select & drop - an inversion of the previously discussed select & pick interaction. In this interaction the user brings an object (in this case a picture) to the screen. By selecting a destination on the screen, the picture moves from the phone to the screen.

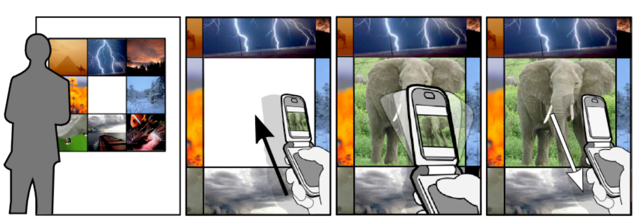


Figure 3. Select & drop using Touch & Interact.

2.2 Advantages

When used as an input device, the phone offers numerous modalities: joystick, buttons, haptic and audio feedback. Rather than supporting only single selections, these modalities can be used to enhance the interaction possibilities. The phone also offers storage capabilities for storing contextual data concerning the user such as required accessibility controls. Storage capabilities can also be used for phone identification, supporting multiple users simultaneously and authenticating users regarding access privileges and billing.

Touch & Interact benefits from direct interaction between a dynamic display and mobile phone whilst using both interfaces in parallel. The main advantage, when comparing this interaction technique with a conventional touch screen, is that the mobile device can show additional, potentially private information. Sharp et al. [7] highlight privacy issues with public screens and describe the “shoulder-surf” - a method attackers use to obtain user credentials. Using Touch & Interact, sensitive information such as user passwords or address information can be displayed on the phone display.

Touch & Interact can be used in many applications in order to improve them. Examples include: interaction with shop windows, vending machines, maps, public displays, interactive surfaces or any other information display.

2.3 Challenges

Input devices such as a mouse provide a very high input resolution that supports the selection of very small targets. When using a finger on a touch screen, the minimal size of the target should correspond to the size of the finger, which in turn, unfortunately also occludes the target. In reality, most touch screen interfaces in the public sector have targets greater than 2.6 square cm [8]. When considering the use of a mobile phone as it is used in Touch & Interact, it is obvious that the input resolution is relatively low and that the phone occludes a relatively large part of the dynamic screen. Still, there are several ways to address these problems (Figure 4). First, it is possible to provide an enlarged version of the selected area nearby, which the user then can use to select a small target (Figure 4.a). Using the approach depicted in Figure 4.b, the user can select a small target by using the joystick in order to iterate between all available targets in the touched area. Figure 4.c shows another approach whereby the touched area is split up into 9 different areas representing the numbers of the keypad; pressing the corresponding key will select the small target. Figure 4.d shows a further approach based on the *Shift* interaction technique [9]. It uses the joystick of the mobile phone in order to control a cursor in the touched area.

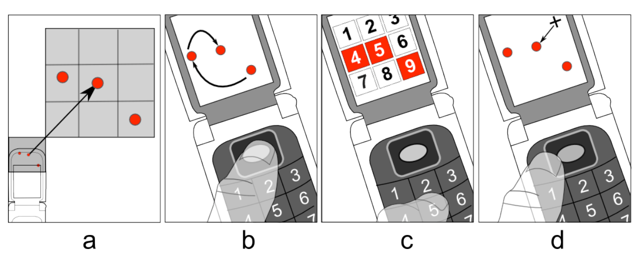


Figure 4. Solutions to overcome the problem of the limited input resolution and occlusion.

3. BACKGROUND

The usage of mobile devices for interactions with static displays (e.g. map) and dynamic displays (e.g. public screen) has been the focus of many research projects in the last decade [6]. When interacting with a static display, the phone usually acts as an information display and is used to provide additional or more up-to-date information to the user. Fitzmaurice was one of the first who designed and discussed applications in which a mobile device is used to interact with such static information displays [10]. He described a map on which the user can point their mobile phone to get additional information about that specific area. Alternately, it is possible to use mobile devices primarily as input devices (e.g. for controlling a cursor on a remote display). An example of this is the Pebbles project where a PalmPilot was used as an input device for the interaction with a PC or a whiteboard [11].

When analysing existing techniques for mobile interaction with displays, it is possible to distinguish between direct/indirect and relative/absolute interaction techniques that work in one to three dimensions and that can trigger discrete or continuous feedback [10]. Touch & Interact is a direct and absolute interaction technique with a two-dimensional input space and continuous feedback.

Using a mobile device to touch objects in order to interact with them is a relatively new concept. Want et al. published in 1999 a prototype which incorporated RFID tags and an RFID reader connected to a mobile device [12]. This prototype was used to interact with augmented books, documents and business cards to establish links to corresponding services, such as ordering a book or picking up an email address. Today, there are many phones available with built-in Near Field Communication chips and these phones are used widely in some Asian countries [13].

Reilly et al. developed and evaluated a system in which a mobile device can touch and select options on a static display [14]. The system used a paper map which was augmented with a set of RFID tags - representing the touchable options. A mobile device, connected to a RFID reader, was used to read these tags in order to get additional information about objects on the map. The important difference with Touch & Interact is that a paper map was used instead of a dynamic display. Consequently, the mobile phone is the only device that can provide additional and up-to-date information. Furthermore, using the system described by Reilly et al., it is not possible to realize sophisticated interaction techniques such as select & pick and select & drop, as described in the previous section.

Aside from touching-based approaches are pointing-based ones in which the mobile phone is used to control a remote cursor or to directly select an object on the remote screen using the phone's camera. In Point & Shoot [5] and SpotCode [15], the mobile phone tracks visual patterns presented by the screen via the built in camera in order to calculate the position and movement of the mobile phone. There are also marker-less, vision-based approaches which analyse the visual information provided by the display or the optical flow when moving the mobile phone [5]. The C-Blink [16] system used the opposite approach. In this system, the mobile phone emitted visual patterns via its display. These patterns are used to the track the mobile phone using a camera attached to a large screen. The tracking information is used to control a cursor on the screen. Forlines et al. describe a further solution whereby a handheld projector is used to project a dynamic display with which the user can interact [17].

Alongside mentioned direct touching or pointing-based interaction techniques exist also a vast set of research prototypes in which a mobile device is used as an indirect remote control. An example for this is the usage of a PalmPilot touchpad in the Pebbles project [11]. Silverberg et al. on the other hand analysed the usage of a joystick (integrated in many mobile phones) as a pointing device for interaction with a remote display [18].

Both Pick-and-Drop [19] and Touch & Interact share the concept of interaction between a mobile device and dynamic screen. However, Pick-and-Drop requires an additional pen which is used as the interaction device. The conceptual model of Pick-and-Drop is that the user picks an object with the pen by clicking on it, the object is stored on the pen, and touching another display with the pen then drops the object.

A further related research area is the usage of interactive surfaces like DiamondTouch [20] or Microsoft Surface [21]. The former concentrates on the usage of a finger as the primary input devices but Microsoft Surface also supports interaction with mobile devices. For example, it is possible to put a mobile device such a digital camera, PDA or mobile phone, on a Microsoft Surface and drag & drop photos or events in order to copy them to or from the mobile device. The difference between Microsoft Surfaces and Touch & Interact is that with Microsoft Surfaces, the user primarily interacts with the interactive surface, and the mobile phone acts primarily as a data container. In Touch & Interact, the mobile phone is the primary interaction device and both displays (mobile phone and dynamic screen) are used in parallel to provide novel interactions, such as select & drop and select & pick.

There exists a manifold of applications and scenarios for the usage of mobile devices to interact with static and dynamic displays. Beside applications already mentioned, the WebWall allows user interaction for participation in an auction or a public opinion poll [2]. Using the Hermes Photo Display, a person can use a mobile phone to interact with this display to upload, manage and view pictures [3].

4. PROTYTPE

A prototype was developed based on previous work [22] in order to compare Touch & Interact with other existing interaction techniques and to build applications based around it.

4.1 Sensing of Touching

Near Field Communication (NFC) technology was used to recognize the location of contact between the mobile phone and dynamic display. Using an NFC phone, it is possible to read information stored on low cost NFC tags. Figure 5a shows the hardware used for the touch-able interface.

The hardware consists of a 10x10 mesh of NFC tags (Trikker BL38 from toptunniste.fi). Each tag had its location in the mesh pre-stored (e.g. 1:1, 1:n or m:n). The tags had a size of 4x4 cm and were considered analogous to a touchable pixel on the display. The corresponding dynamic display had a size of 50x50 cm (including tag spacing) and an input space of 10x10 touchable pixels. As the input resolution was used to support a preliminary exploration of the potential for the concept, it should not be considered the maximum input resolution supported by the technology. For instance, RFID tags unveiled by Hitachi have a size of $0.4mm^2$; these would provide much higher input resolutions [23]. A Nokia 6131 NFC phone was used which has a read/write range of 0-5 cm and a width of 4.8 cm - similar to that of NFC tags we used.

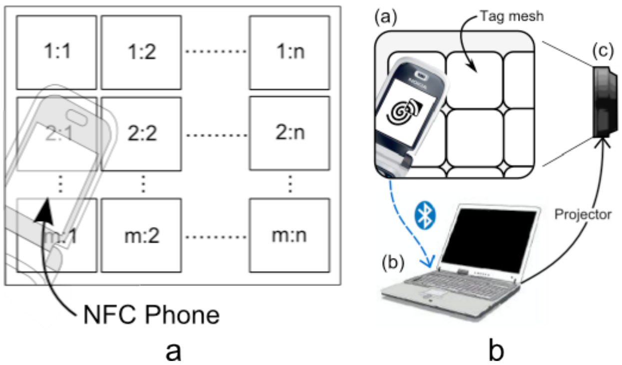


Figure 5. a - NFC phone touches mesh of NFC tags, b - Emulation of a touchable dynamic display.

4.2 Dynamic Display

After designing and developing the NFC sensing, a video projector was added to the system in order to project the user interface (running on a laptop) onto the mesh of NFC tags (Figure 5b). This laptop acts as a server and receives messages via Bluetooth from the phone, such as *"tag m:n"* was touched. The server processes the actions received from the phone, updates the state of the system and provides visual feedback of the state change using the projector and mobile phone. A thin paper layer covers the tag mesh for projection clarity. Because this layer covers up the location of the tags, a virtual, semitransparent tag overlay is projected onto the paper as can be seen in Figure 5b.

The usage of a projection in this prototype has the disadvantage that the phone and the arm of the user can occlude parts of it. Commercial implementations might use transparent RFID tags or tags attached to the back of a display. Today, it is already possible with certain displays (e.g. a MacBook display) to attach tags on the back of this display which can be read through the display using an NFC phone.

4.3 Implementation

The application running on the mobile phone was implemented in Java ME (CLDC 1.1 / MIDP 2.0). The Contactless Communication API (JSR 257) was used for accessing the NFC capabilities of the phone and the Java APIs for Bluetooth (JSR 82) were used for the communication with the laptop. The server application (running on the laptop) was implemented in Java SE. The Bluecove API was used for the communication with the Nokia 6131 NFC and the Java tag objects used in the application were designed around the concept of JButtons for Java Swing.

4.4 Interaction

When developing the prototype, the following basic interactions were implemented:

- **Hovering** – Using the hovering technique, a phone can be moved within read range of a tag and additional information is displayed on the phone display.
- **Selection** – When a tag is hovered, the user can press a specified key on the phone to select the tag.
- **Multi-selection** – If the user holds the key, they are able to select multiple tags.
- **Polygon-select** – Polygon points can be plotted by holding a specified key and touching the appropriate tags. When the key is released, the tags inside the polygon area are selected.
- **Pick-and-drop** – Items selected are 'picked up' using the phone and can be dropped elsewhere on the screen.
- **Remote Clear** – This interaction de-selects any currently selected tags remotely. Incorporating remote interactions into the prototype reduces arm fatigue which builds with prolonged use with pointing interactions.

The phone display is used to show complementary information to the user such as additional help information (displayed when particular tags are hovered). Haptic feedback notifies the user to look at the phone display in response to an event; for example, alerting the user that help is currently displayed on the phone. Haptic feedback and with audio feedback are used for more assertive feedback during tag selections. Moreover, audio feedback also alerts the user of possible errors during interactions.

5. COMPARISON

Two prototypes were developed and evaluated in order to analyse the advantages and disadvantages of Touch & Interact and to compare it also with existing interaction techniques. The first study is a predominantly quantitative comparative study which contrasts three types of interaction techniques regarding performance. The second study based is primarily qualitative, focusing on usability aspects.

As discussed in the introduction are a conventional touch screen that is combined with a mobile phone (referred to in the study as *finger interaction*) and a conventional display, controlled remotely with a mobile phone (referred to in the study as *remote interaction*). Both are alternative solutions that can be used to overcome the limited visual output capabilities of mobile phones. The aim of the first study was to identify the relative performance between remote interaction, finger interaction and Touch & Interact for basic target selections. In this experiment, performance is represented by selection times and selection error rates.

The aim of the second study was to further the first study results for finger interaction and Touch & Interact based on a concrete application. The first part of this study comprises of a quantitative comparison and the second part compares the two interactions from a qualitative perspective, focusing on usability aspects.

Twelve paid participants, (6 male) between the ages of 19 and 46 (a group mean age of 27) took part in both studies. Participants had varying computing and mobile phone experience and were recruited at a Lancaster University (students, administrators, secretaries). All of them were right handed and all but one owned a mobile phone.

6. COMPARISON: SELECTION

6.1 Prototype

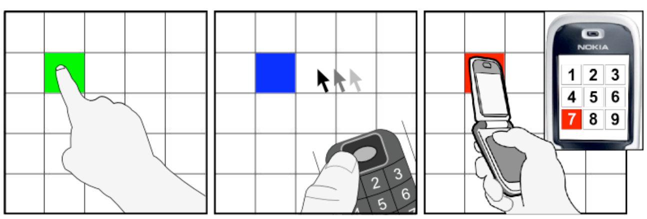
Prototype 1 supported simple two-dimensional target selection exercises using finger interaction, remote interaction and Touch & Interact. The prototype generated a sequence of thirty pseudo-random (to keep a constant distance between targets) targets for each trial. Figure 6 shows each selection technique using the three interaction techniques. During trials, a single target was displayed at a time and once selected; the target disappeared and was replaced by a new target in a different position. There were two target sizes ($50mm^2$ and $16.7mm^2$) and two distances for target separation (100mm and 345mm). The prototype automatically randomly selected a sequence of twelve trials, each with a defined type of interaction, target size and separation distance. The prototype changed the colour of the target depending on the system. This made it clear to each participant which type of system to use.

A combination of a SMART Technologies Inc. smart board and projector was used as the dynamic display for all tested interaction techniques. The display area for the prototype was 50x50 cm (450 x 450px).

Finger interaction. The touch screen functionality of the SMART Technologies Inc. smart board was used for the implementation of this interaction technique.

Remote interaction. The Nokia Presenter [24] running on Nokia 6131 was used for the implementation of this interaction technique. Using this, the joystick of the mobile phone can be used to control a cursor on a remote screen control via Bluetooth.

Touch & Interact. Touch and Interact used the implementation described in section 4, employing a 10x10 mesh of NFC tags and a Nokia 6131 NFC phone. The small target size requires an input resolution three times that supported by the 10x10 mesh. Therefore, an intermediate action was required to select a target (inside the tag currently read) using the phone keypad. When the phone reads a tag, the phone display highlights the number to be selected using the keypad (Figure 6c). This display disappears when the phone is move out of read range. Vibration was used to confirm a selection.



a b c

Figure 6. Prototype 1: a - finger interaction, b - remote interaction and c - Touch & Interact.

6.2 User Study

6.2.1 Experimental design

The experiment had a repeated measures, within-participant factorial design 3 x 2 x 2 (*interaction techniques* x *distance* x *size*). The experiment was based on the two-dimensional ISO9241 part 9 tapping test (used for human performance modelling for basic point-select tasks) [25].

The independent variables were *interaction technique* (remote interaction, finger interaction and Touch & Interact), *distance* (short: 100mm and long: 345mm) and *size* (large: $50mm^2$ and small: $16.7mm^2$). Index of difficulties ranged from 1.56 bits to 4.44 bits.

The factorial design produces twelve completely randomized trials - each consisting of thirty target selections. On completion of the trials, a post study survey was conducted. The following hypotheses were predicted for experiment 1:

- (H1) Highest performance by finger interaction in all corresponding trials
- (H2) Lowest performance using remote interaction in all corresponding trials
- (H3) Similar error rates for all interaction techniques.

The survey instrument uses a variation of ISO9241-9 questions using a five point scale [25]. This survey covers issues on physical operation and additionally the survey requests participants rank each interaction technique.

6.2.2 Dependent measures

Touch & Interact interactions are not suitable for throughput measurements (used in the index of performance in Fitts' law tasks) as the effective width of the small target does not directly correspond to the pointing accuracy of the phone. In replacement, the first dependant variable is *Target Selection Time*. Data was logged for each target selection; the mean time began after a training period. The training period consisted of the first fifteen out of a total of thirty selections for each trial. Data before the mean time helped to reveal any learning effects.

The second dependant variable is *Error Rate*. Each time the target was missed, an error was logged. As with the timings, the average error rate began after fifteen out of thirty selections. The Touch & Interact interaction technique had additional error logging for incorrect key presses - applicable to the small target selections.

6.2.3 Procedure

Participants were presented with a random series of target selection trials and were told to select the targets as quickly and accurately as possible. Each trial comprised of a different combination of target size, distance and interaction technique. When participants began each trial, they were presented with a single target (used for homing and activating the data logging). Once selected, the target disappeared and a new target appeared in different area on the projection (in accordance to the distance setting). The process repeated until all thirty targets were selected. Once all twelve trials were complete, participants were asked post study questions from the survey.

6.3 Results

6.3.1 Measurements

A 3-Way Repeated Measures ANOVA was used to analyse the performance times for each interaction technique. Results dependant only on the *interaction technique* show a significant difference (Greeenhouse-Geisser) ($F_{1.07,11.74} = 172.13$, $p << .001$).

Target Selection Time data (*in seconds*) shows that remote interaction has the highest selection time (M = 4.05, SE = 0.21), Touch & Interact an intermediate (M = 1.72, SE = 0.07) and finger interaction has the lowest time (M = 1.01, SE = 0.03). Planned contrasts show that finger interaction is significantly faster than both remote interaction ($F_{1,11} = 185,82$, $p << .001$) and Touch & Interact ($F_{1,11} = 156.46$, $p << .001$). Using these results, H1 (Highest performance by finger interaction in all corresponding trials) is accepted as finger interaction performs significantly best in all corresponding trials. Contrasts also prove H2 (Lowest performance using remote interaction in all corresponding trials) to be true as remote interaction is significantly slower than Touch & Interact ($F_{1,11} = 154.21$, $p <<$ .001) and finger interaction ($F_{1,11} = 185.82$, $p << .001$).

Bonferroni adjusted pairwise comparisons show that the selection time of Touch & Interact is overall 41% (0.7 seconds) slower than finger interaction and 135% (2.3seconds) faster than remote interaction.

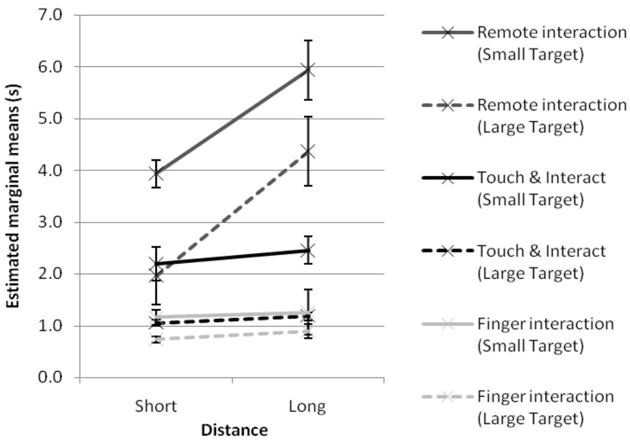


Figure 7. Average selection time for targets with 95% confidence intervals.

The ANOVA analysis shows that distance changes ($F_{1,11}$ = 232.53, p << .01) and size changes ($F_{1,11}$ = 416.79, p << .001) prove to be significant regarding interaction technique times. The effects of both size and distance on Touch & Interact (Figure 7) shows that the size effect is expectantly considerable and constant for both distances - 109 % performance decrease at short distances and 108% at long distances. Distance has a small and constant effect of 12 % with both target sizes The result consistency and effect of target size is due to the constant time for intermediate keypad interactions (required for small targets), (M = 0.74, SE = 0.11) for short range and (M = 0.74, SE = 0.99) for long range targets.

With remote interaction, increased distance has a greatest effect due to performance drops of 123% (when using large targets) and 51% (when using small targets). Finger interaction shows the size of the targets having a greatest effect: 58% (at short distances) and 41% (at long distances).

The study prototype logged the sequence of trials that each user performed, thus learning effects could be analysed. On graphical analysis of learning effects with all three interaction techniques, the improvements were occasionally evident during the first few selections for Touch & Interact and remote interaction. The sample data for both interaction techniques showed higher constancy of times during the second half of the trials rather than significant improvements. Learning effects regarding error rates also showed no substantial signs of improvement, even from the very beginning, also little pattern with regards to consistency.

The 3-Way Repeated Measures ANOVA for error rate analysis shows there was no significant effect between the three interaction techniques - largely caused by data variability ($F_{2,22}$ = 2.02, p = .157). This result validates H3 (similar error rates for all interaction techniques) to be true. Size had a significant effect ($F_{1,11}$ = 15.57, p < .003) on error rates (Figure 8), predominantly for Touch & Interact and finger interaction. Remote interaction is influenced by distance for large targets. This is likely due to acceleration of the curser over long distances and patience of the user.

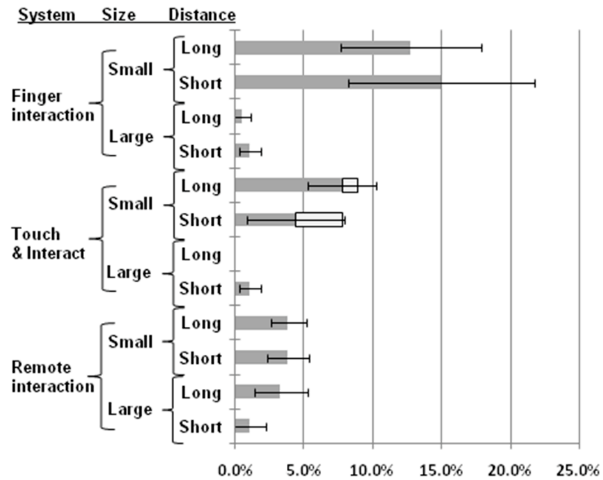


Figure 8. Average error rates for all trials with 95% confidence intervals

ANOVA results show that finger interaction and Touch & Interact are significantly affected by the size of the target. The sizeable error rate for small target sizes with the touch-screen is likely to be result of occlusion caused by the finger. Touch & Interact also has a considerable increase in error rate. The stacked bars show the augmented errors from erroneous number selections (using the keypad). The differences between the Touch & Interact and finger interaction are not significant in accordance to ANOVA analysis. Figure 8 reveals that finger interaction has the highest error rate for small targets by some margin.

6.3.2 User Feedback

The 1-Way Friedman's ANOVA shows that the type of interaction significantly affected the survey results ($\chi^2(17)$ = 148.81, p << .001). Wilcoxon follow-up tests are used to analyse the results in more detail and showed mainly significant results. The only non-significant results were:

- All interaction techniques for Physical Effort (p > 0.05)
- Touch-screen vs. NFC for Overall Ease (p > 0.05)

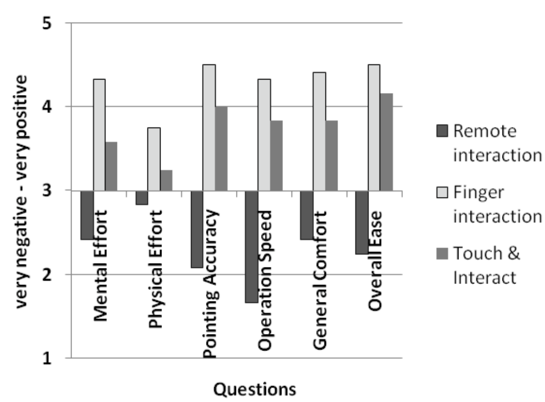


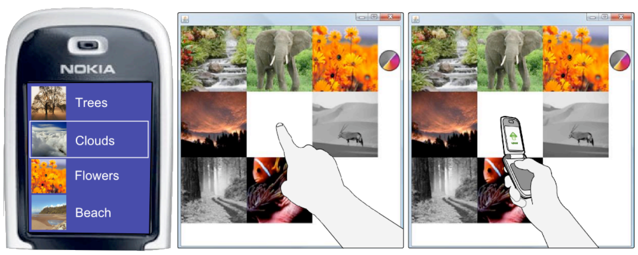
Figure 9. User feedback for selection experiment.

Figure 9 shows that finger interaction performs best for all questions and Touch & Interact has also positive results for all questions. The main variation for the *Physical Effort* question is result of participant's views on whether many finger movements (used for the remote interaction) constitutes to a smaller number of arm movements (required for Touch & Interact and finger interaction). The remote interaction has negative results for all questions, in particular, the perceived speed of the interaction technique. The rankings results showed all twelve participants ranked remote interaction as the worst technique, eleven ranked Touch & Interact as the intermediate technique and eleven ranked finger interaction as the preferred technique.

7. COMPARISION: PICTURE BOARD

7.1 Prototype

Prototype 2 is a digital picture board system that uses the same SMART Technologies Inc. smart board, Nokia 6131 NFC, tag configuration and display area as in prototype 1. The same software tools were used for Bluetooth communication (to support messaging and data transfer). Figure 10a shows the phone system which allows the user to scroll through a list of picture thumbnails with associated names.



a b c

Figure 10. a - scrolling images, b - finger interaction with the picture board, c - Touch & Interact with the picture board.

Uploading a picture varies depending on the interaction technique used. Using the finger interaction (Figure 10b), once a picture has been selected on the phone, it can be uploaded to the board by double-clicking in a blank area on the board. Alternately, double clicking on a picture on the board will download the picture to the phone. Uploading using Touch & Interact (Figure 10c) requires the user to read a tag on a blank area on the board and confirm with a key press. If a tag in the bounds of a picture is read, the same process is used to download a picture to the phone. The prototype supports a greyscale tool which can be applied to the pictures. This process also differs for each interaction technique. Using the finger interaction, the greyscale widget can be dragged over a picture and dropped to apply. Using Touch & Interact, the widget can be *picked up* onto the phone and dropped on picture to apply.

a b c d e

Figure 11. Touch & Interact screens

Figure 11 shows the Touch & Interact screens for prototype 2: screens (a) and (b) show the upload and download screens. These prompt the user to upload/download pictures to or from the phone. Screen (c) indicates that the user can pick up a tool. Screen (d) shows the greyscale tool is currently *picked up* and screen (e) indicates the tool can be applied to a picture.

7.2 User Study

7.2.1 Experimental design

The experiment had a repeated measures, within-participant design. A picture board system was implemented for the experiment whereby users must perform six trials with each interaction technique. The independent variable was *interaction technique* with two levels (finger interaction and Touch & Interact). The variable was counterbalanced between participants. The post study survey follows the completion of the trials and uses a variation of the *Ease of Use* model for user acceptance of information technology [26]. The survey uses a 5 point ranking for each question. This survey realizes the degree to which each interaction technique is perceived as difficult to use and additional questions elicit the level of user-satisfaction using each. All participants gave consent to video recording during the study. The following hypotheses were predicted for experiment 2:

- (H1) No significant time difference in trials between both interaction techniques. The performance of the interaction techniques is less critical for this experiment as there is greater perceptual and cognitive load on the participant.
- (H2) Highest overall usability and user-satisfaction ratings for Touch & Interact due to the advantage of using the functionality of the mobile phone.

7.2.2 Dependent measures

The only dependant variable used in experiment 2 is *Overall Performance Time* for each trial. Timings are also logged for intermediate actions (*Upload, Greyscale picture,* and *Download*) for possible further analysis. The study is for the most part focused on user-satisfaction and usability; consequently the performance values are supplementary to the survey. The average timings began after a training period which consisted of the first fifteen out of a total of thirty selections for each trial.

7.2.3 Procedure

Each trial involved searching for and uploading six pictures (randomly selected by the system) from the phone to the picture board. Once uploaded, the greyscale tool was applied to each. Finally, the participants downloaded six pictures of their choice to the phone and visually confirmed each download with the thumbnail on the phone display.

7.3 Results

7.3.1 Measurements

A Paired-Sampled T-Test was used to analyse the overall time comparisons between the Touch & Interact and finger interaction. The results were expectantly non-significant. The trial times for Touch & Interact (M = 7.34, SE = 0.57) were higher than the finger interaction (M = 6.71, SE = 0.85) by a difference of (M = 0.63, SE = 0.82). However, the high standard error yields inconclusive results. The time difference for corresponding pick/drag and drop interactions between Touch & Interact (M = 1.96.40, SE = 0.13) and finger interaction (M = 2.43, SE = 0.37) was (M = 0.48, SE = 0.37). However, the comparison is not significant ($p > .05$).

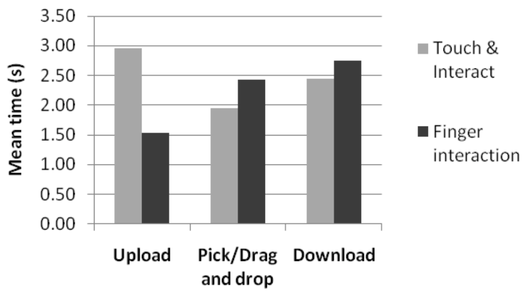


Figure 12. Picture board mean performance times for trials

Observation from the video capture indicates that the main reason for the large upload times (Figure 12) with Touch & Interact is due to users pressing the upload key before the tag is read. This key is also responsible for selecting/de-selecting the thumbnail, as a consequence, when the phone was not in range, the thumbnail would de-select the thumbnail rather than upload. Simply moving the de-selection operation to another key would dramatically reduce the upload times and overall combined mean.

7.3.2 User Feedback

The 1-Way Friedman's ANOVA shows that the survey results (Figure 13) were not significantly different ($p > .05$).

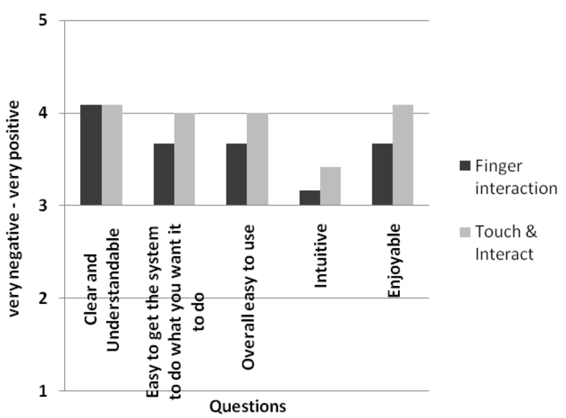


Figure 13. User feedback for experiment picture board.

An important addition to the survey is the ranking for a preferred interaction technique with supplementary reasons. Four participants were in favour of finger interaction and eight in favour of Touch & Interact. When participants were asked their reasons for their ranking choice, the following results were elicited:

Most participants found pick and drop interactions in Touch & Interact easier then drag and drop using finger interaction. A contributing factor was occlusion of the target picture by the participants hand and arm. Using pick and drop, participants can move their hand or arm away from the display to avoid occlusion. It can be argued that pick and drop can also be implemented with a touch-screen, providing less feedback. However, it seemed more interesting to compare the two different styles as experiment 1 already shows the difference in pointing times between the two interaction techniques.

Intermediate help screens made actions more procedural, providing high visibility of interaction status and better error prevention. This is shown by the Touch & Interact results of the *Overall Ease to Use* and *Easy to get the system to do what you want it to do* questions (Figure 13). These questions are part of the Ease of Use model of Individual Acceptance [26].

Although unfamiliar with the technology, many participants found the touching interaction between the phone and public screen an intuitive way to drop (send) pictures. The same applies to picking (uploading) pictures using the phone.

Many participants regarded Touch & Interact as fun to use. This is shown by the results for the *Enjoyable* question (Figure 13). Participants in favour of the touch-screen preferred the familiarity of touch-screen interaction. One participant also preferred not to have a phone as an intermediate during interactions.

Video observations showed that most participants change hands between scrolling on the phone and interacting using finger interaction. This was not normally true for downloading pictures to the phone where no phone interaction was required. Participants, who did not change hands during phone interaction, used both hands on the phone when scrolling. In this case, the phone would drop to the user's waist where they find using it more comfortable to use. This forces the user to look down when viewing the phone and creates large context switches between the phone display and the main screen. Context switches are smaller with Touch & Interact as all participants used one hand for scrolling and the phone felt comfortable using the phone higher and closer to the screen. Touch & Interact seemed to unify the scrolling and screen interactions as participants would keep a similar body posture and position for both phone and screen interactions.

8. DISCUSSION

The results for experiment 1 confirm all three hypotheses. Finger interaction performed best, followed by the Touch & Interact. Remote interaction performed worst, by a significant margin, in all trials. The ordering of respective interaction techniques in terms of performance was expected, but the primary aim is to analyse the extent of the difference and where Touch & Interact fits between the two alternatives. Results show that Touch & Interact is a great deal closer to finger interaction performance than remote interaction performance.

Target size had a substantial effect on performance, particularly for Touch & Interact and distance had a substantial effect on remote interaction. Additionally, size is a crucial factor determining error rates, particularly for finger interaction and Touch & Interact. Further results for the effects of distance and size on the interaction technique show the impact of the intermediate action, required to select small targets using Touch & Interact. Although the overhead approximately doubled the interaction time, the impact is constant and proportionately low (considering the low pointing times with large targets). Despite this overhead, Touch & Interact is 135 % faster (overall) than remote interaction. The first experiment demonstrates the performance of Touch & Interact over remote interaction. Remote interaction was therefore not included in the second experiment, which focuses on usability aspects rather than outright performance.

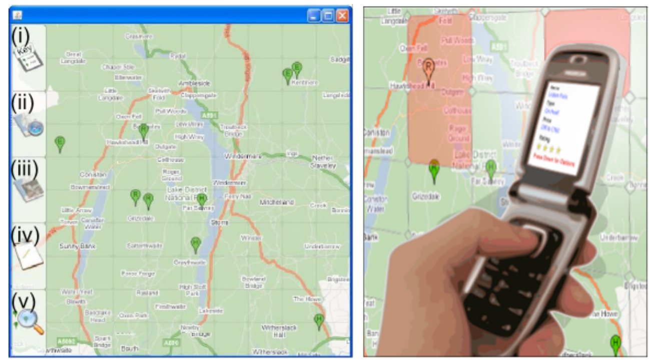
With regards to error rates, the ANOVA analysis resulted in non-significant results for the type interaction technique largely due to variability of the data. However, the graphical representation for the sample data (Figure 8) showed a substantial increase with finger interaction and Touch & Interact - finger interaction with the highest error rates. When participants used Touch & Interact, observations revealed that several were inclined to point the phone specifically at the small target rather than the tag, which in cases, resulted in the phone reading an adjacent tag. With correct use of the phone for selection, error rates would be significantly reduced.

The results of the second experiment conformed to the hypotheses. The results of the survey show better results for Touch & Interact, especially for overall ease of use, intuitiveness and enjoyment. However, the ranking results show an evident participant preference in favour of Touch & Interact. The number of participants who ranked Touch & Interact their preferred interaction technique was double the number for finger interaction. Observations from the video footage reinforce the ranking results, as nearly all participants have better posture and orientation when using Touch & Interact. This is not necessarily true for normal touch-screen interaction without a phone but is the case when the user has to mediate between both the phone and large screen. This is further impacted by large context switches between the phone and screen using the touch-screen.

9. APPLICATION

In order to use the Touch & Interact interaction technique in a more practical context, we developed a tourist guide prototype (Figure 14) which could be installed in a tourist office, a train station or nearby a crossing. Example uses of the prototype are planning a day trip or searching for a nearby restaurant - taking advantage of the large screen. Through phone interactions, users are able to perform zooming and panning operation on a Google map of the area. For example, when the joystick button is pressed up and the display is touched at a given location, then the map zooms in (focused on the location). Pressing another key and touching the map, the user is able to move to map up, down, left and right. Using the application, the user is additionally able to view information about places of interest (represented by markers on the map) and build an itinerary of places they would like to visit. This information can be either displayed on the screen of the mobile phone itself or can be displayed by the public screen, whereby parts of the map are then overlaid with this information.

The side menu, displayed by the dynamic screen (Figure 14) can be switched on or off by pressing a mobile phone button. Help information is displayed on the phone display when each menu option is hovered. The menu provides a map key (Figure 14a(i)) as the top menu option. When hovered, the map key is displayed on the phone, and indicates what each marker icon represents. Figure 14a(ii) changes the application mode to *view* mode. In this mode, the phone key assignments change for viewing and panning the map. In cases where they are zoomed in, a satellite display also appears on the phone to show the user's position. Figure 14a(iii) toggles the map satellite imagery on or off. Figure 14a(iv) provides itinerary functionality. When this option is hovered, the user can add markers to the itinerary which have previously been picked up by the phone. By pressing an alternate phone key, the itinerary can be viewed publicly or privately using the phone display. The final menu option (Figure 14a(v)) allows the markers to be filtered by category, for example, filtered to show only restaurants.



a b

Figure 14. Tourist guide prototype, a - information showed on the public display, b - mobile phone selecting point of interest

When a tag containing a marker is hovered, the phone display shows additional information about the marker such as name and rating. Whilst hovering, the user can press a key on the phone to enter a corresponding context menu. The context menu options allow extra information to be retrieved from the marker, retrieval of a VCard from the marker and a distance calculation to another marker. If a tag is selected that contains any markers, they too are selected. When markers are selected, their names are displayed as a list on the phone display. The phone also vibrates to indicate that the user has picked up the markers onto the phone.

In order to analyze the prototype's usability and to elicit ideas for further development, we evaluated this prototype in a preliminary user study. The user study was predominantly qualitative, comprising mainly of observations and subject feedback comments.

A group of ten participants (nine males, one female) were chosen to take part in a within-groups, cooperative evaluation. Participants had an average age of 25, each was asked to complete various trials. The first trial was to build an itinerary for the day. This trial involved various interactions and was used to understand the extent to which each subject can perform a relatively rich task using the prototype. The next trial requested the user selects a number of markers which could be executed using a number of selection methods. Each participant started hesitantly but quickly reached an autonomous and comfortable level. Many participants enjoyed tentative interactions such as hovering markers and the contextual help provided. Participants were pleased with the effect of the haptic and audio feedback to validate actions such as closing the application and selections. Participant responses to the effectiveness of the different types of feedback were positive. On an interval scale between one (very ineffective) and five (very effective) they answered with a mean of:

- 4.1: How effective is the dynamic display as opposed to a static map?
- 3.6: Does the phone display complement the large display?
- 4.0: How effective is the tactile and audio feedback?

The preliminary results show that the participants definitely see the advantage of combining the displays of the mobile phone and the dynamic screen. Furthermore, all of the participants said that they would use such a system outside the evaluation.

10. CONCLUSION

Touch & Interact is a new interaction technique that can be used to overcome the limited screen size of a mobile device (a disadvantage when using map, browsing or photo applications) with the usage of a dynamic screen. Through the interplay of the two screens, mobile device and dynamic screen, richer interaction techniques like select & drop or select & pick can be realized that offer an added value to the user. Moreover, using mobile phones in interactions increases interaction possibilities through phone input modalities, additional feedback, contextual potential and storage capabilities. Our experimental results show that the selection time of Touch & Interact is comparable to a touch screen alternative and is much faster than using the phone's joystick to control a cursor on a remote screen. In addition, the second experiment shows the advantages of Touch & Interact regarding ease of use, intuitiveness and enjoyment. Moreover, most users preferred this interaction technique when comparing it with a solution based on a touch screen.

We currently work on the further development of the implementation of this system using tags attached to the back of a screen rather than using a projection. Furthermore, we plan to deploy the application described in section 9 in a nearby village in order to test Touch & Interact and the tourist guide application in a more practical context. This will be a longitudinal study, thus reducing possible novelty effects of Touch & Interact and showing the effects of user-familiarity with the interaction technique over time.

ACKNOWLEDGEMENT

The presented research was conducted in the context of the Multitag project [27] which is funded by DoCoMo Euro-Labs.

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