Exploring Expressive NFC-based Mobile Phone Interaction with Large Dynamic Displays

Robert Hardy, Enrico Rukzio
Lancaster University
Lancaster, UK
e-mail: {hardyr, rukzio}@comp.lancs.ac.uk

Matthias Wagner, Massimo Paolucci
NTT DOCOMO Euro-Labs
Munich, Germany
e-mail: {wagner, paolucci}@docomolab-euro.com

Abstract—**Inherent obstacles in current mobile applications are the limited input and output capabilities of mobile phones. In many ways, e.g. in terms of display capabilities and processing power, today's mobile phones are quite versatile and provide opportunity for a multitude of new applications. Conversely, mobile phones will always be somewhat limited by certain form factors that are intrinsic to their compact design. For instance, small screen sizes make it difficult to visualize and manage applications that require a large amount of information on-screen for display and interaction. This paper reflects on our work accomplished when developing a new NFC interaction technique in which a mobile phone can be used as a direct input device for interaction with large dynamic displays. Using the (previously published) touch & interact interaction technique, the user touches the display with their mobile phone to perform an action. Beyond expressive interaction, an advantage of this approach is that large displays can provide spatial awareness while the mobile phone uses its capabilities to enhance the interaction (e.g. providing privacy and new interaction possibilities). We give technical details of our implementation and reflect on the most salient findings from three user studies, two of which elicit very promising results regarding selection performance and usability when compared with current, existing alternatives. Throughout the development of these prototypes, various interaction caveats have been identified, which are outlined in this paper, that promise to influence future NFC applications and interaction paradigms.**

Keywords- mobile, NFC, touch, display, interaction.

I. INTRODUCTION

The emerging versatility and capabilities of mobile phones creates many new opportunities for mobile applications. However, current mobile user interaction restricts developers from taking advantage of these opportunities. A key limitation of these devices is typically the compact display which limits the user's ability to view and interact with a large amount of information at once [1]. This is an important issue as phones are ever-improving in computing power, sensory, and connectivity features, but are constantly restricted by their user interface. Primary examples of such mobile applications that require spatial-awareness are web and location-based applications, which are emerging as omnipresent, owing to the advent of 3.5G and GPS services. Unfortunately, the limited display capabilities of mobile phones can only provide a narrow purview of such information, acting essentially as a peephole display.

The advantage of using a dynamic display (e.g. projection, LCD, plasma or TFT) is the ability to show dynamic information, thus providing a broader scope for applications. Updated information does not require re-manufacture of a static display (e.g. advertisement poster), rather simple data manipulation. In addition, variable data such as special offers, transport times, weather and sport scores can be supported. Furthermore, interfaces can take multiple views which help to manage large volumes of information, and can show different perspectives of the information based on user access privileges or viewing preference.

In this paper, we present the implementation of the touch & interact interaction paradigms, as well as related prototypes. Complementary to earlier publications [25, 26], we focus on the technicalities of the implementation and reflect on the technical impact of the user studies in detail.

Touch & interact is an NFC-based interaction technique that allows a user to touch a dynamic display with their mobile device in order to perform an action. This approach works towards the envisioned interaction in Fig. 1 – supporting fluid, gesture-based interactions comparable to touch-screen interaction.

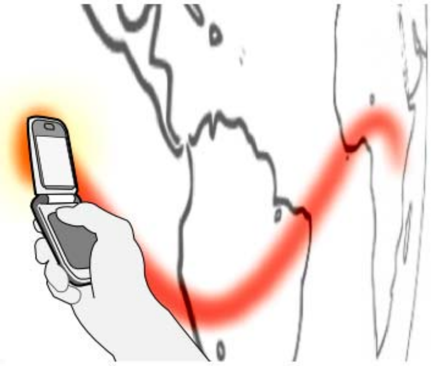

Figure 1: The envisioned touch & interact approach

The advantages of the touch & interact approach are the following:

- The touch-based interaction is intuitive – touching the interface and phone is especially intuitive when transferring data between them.
- The output capabilities of the mobile phone (visual, audio and vibration) and the large display (visual) can be used in parallel to enhance interaction by, for example, providing more assertive feedback.
- The use of a dynamic display has many advantages over static displays. For example, when using a static display,

(e.g. a paper poster) dynamic data (e.g. prices and transport timetables) must be shown on the phone. Such reliance on the phone display is only a partial solution when trying to overcome the limited visual output of the phone.

- Large displays can be used to show public information and the mobile phone display can present private information (e.g. credit card and address details). Ensuring privacy with public displays is a popular subject; Sharp et al. [22] highlight privacy issues with public screens and describe the "shoulder-surf" – a method attackers use to obtain user credentials.
- The costs of the NFC tags needed for the developed of such system, when purchased in bulk, are very cheap. This advantage leads to the possibility of creating very large interfaces for collaborative environments (using the phone's storage to identify and authenticate users in such a scenario). Regarding deployment of a public display, large size touch screens (approximately 42 inch) can expect to retail around £4000 [23]. Even using a mirror projector (e.g. NEC WT610 [24]) the hardware costs are less than half, whilst also providing screen sizes of up to 100 inches. Moreover, the robustness of the tags makes them less susceptible to vandalism than alternatives, e.g. a touch screen.
- The mobile phone adds several input capabilities to the large display. For example, the key-pad could be used to insert passwords (rather than using an on-screen keyboard in the case of a touch-screen).
- Mobile phones can also provide user or contextual data that is relevant to the application (e.g. for personalization of the application interface) and can be used to take data away from the display (e.g. a navigational route as reference).
- Regarding deployment, touch & interact could be installed at locations such as shop windows, vending machines, maps, public displays, interactive surfaces or any other information display. Deployment potential is enhanced by the de-coupling between the input (NFC tag mesh) and the display, and the read-range of the tags. For the latter, the tags could be placed, e.g. behind a shop window and support NFC input through the window.

The paper is organized as follows. The next section discusses the background work relevant to the problem domain. The architecture of our touch & interact prototype then follows. This leads onto a description of a tourist information application that builds on touch & interact. Subsequently, we discuss the findings of three user studies, two of which were used to compare touch & interact with existing public display interaction technologies. Closing the paper is a summary of our conclusions drawn from the work.

II. RELATED WORK

A popular research interest for increasing display real estate is through the use of displays (e.g. projections or screens) found in public space, office environments and smart homes [9, 10]. Such displays are becoming much more widely deployed as a result of falling costs, and several direct and indirect mobile 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) [2, 3]. Fitzmaurice was the first who designed and discussed applications where a mobile device was used to interact with information displays [4]. A prominent example for the implementation of such a direct interaction technique is C-Blink in which the user points onto a remote display in order to control the mouse pointer on the device [5]. Research conducted by Rukzio et al. compared different techniques for mobile interaction with remote objects and showed the advantages of touch-based interactions when in close proximity to the object [11, 12]. Reilly et al. were the first to develop and evaluate a system in which a mobile device can touch and select options on a passive display [6]. The latter was a paper map that was augmented with a set of RFID tags representing the touchable options. A mobile device, which was connected to a RFID reader, was used to read these tags in order to get additional information about objects on the map. What's more, the importance of active NFC has been realized in Japan with the PitTouch octopus [13]. PitTouch Octopus contains a 4x5 grid of twenty PitTouch readers/writers for interaction with passive NFC phones. A used-car purchasing application is demonstrated where each row of readers/writers represents various buying criteria.

A further related research area is the usage of interactive surfaces like DiamondTouch [14] or Microsoft Surface [15]. DiamondTouch is original in that it supports touch-based interaction via the user's finger, but also identification of respective interacting users. Microsoft Surface makes use of multi-touch interaction, which is combined with object recognition. However, the difference between Microsoft Surface and touch & interact is that the object is the primary interaction device rather than the user's finger.

III. SYSTEM MODEL

A. *The Hardware Architecture*

A touch & interact interface has been developed in order to test this interaction technique and to develop corresponding applications. Near Field Communication (NFC) technology [7] was used to recognize the location of the display the user has touched with their mobile phone. Using an NFC phone, it is possible to read information stored on a low cost, passive NFC tag.

Fig. 2 shows the hardware used for the touch-able interface, which consists of a matrix of NFC tags providing information about their location such as *1:1, 1:n* or *m:n*. In our prototype, we used a 10x10 matrix of NFC tags whereby each tag had a size of 40x40 mm and is analogous to a touchable pixel on the display. Aggregating the size of the tags, the corresponding touchable area is 40x40 cm and an input space of 10x10 touchable pixels. A Nokia 6131 NFC phone was used with a read/write range of 0-5 cm and width of 48 mm, similar to the width of the NFC tags we used.

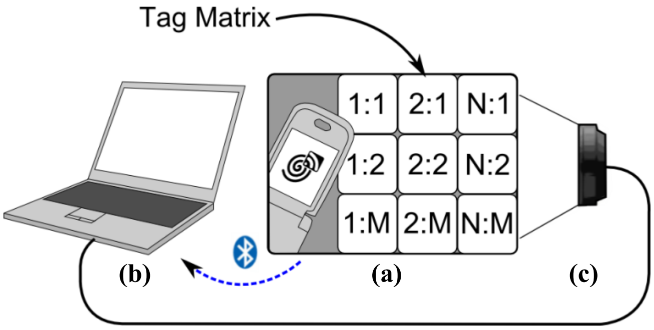

Figure 2: The hardware architecture

After designing the basic multi-tag interface, a video projector was added to the system in order to project the user interface (running on a laptop) onto the tag matrix (see Fig. 2). The 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. It is assumed that the interaction will work with various types of displays and the tags have already been proven to read through an LCD display. A thin paper layer covers the tag matrix for projection clarity. As this layer occludes the location of the tags, a virtual, semi-transparent tag overlay is projected onto the paper. Using this system, the NFC mobile phone behaves as a smart stylus for interaction with the display and dynamic feedback (according to the user’s interaction) is projected onto the matrix of tags or provided by the mobile phone.

The mobile phone application 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 and the Bluecove API was used for the communication with the Nokia 6131 NFC. The server mapped the physical NFC tags to a virtual representation of the tags. The virtual tags were designed around the concept of JButtons for Java Swing. The advantage of storing a reference to the virtual tags on the NFC tag, rather than the actual data itself, is that the role or function of the tag is dynamic. For example, the tags could be list items, buttons, table cells, radio buttons, etc. These roles can be applied instantly and whenever it suits the application. The dynamic tag functionality also works in concert with the dynamic display, as changes in functionality of the tags will also typically require a change in the tags’ appearance on the display.

A bespoke tag event-model was implemented instead of adapting a mouse or keyboard event-model for the prototype. The event-model was designed to be generic so future developers can customize the model to the specific needs of their application and possibly add new interactions.

B. *The Supported Interactions*

The currently supported interactions are concise, yet are sufficient to deal with a range of functionality. Their descriptions follow.

Hovering – Using the hovering technique, the phone can be moved within read range of a tag and additional information is displayed on the phone screen.

Selection – When a tag is hovered, the user can press a specific 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 specific 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.

Context menu – This context menu is displayed on the phone rather than the large display. Using the phone’s directional keys different options can be selected. This method reduces option occlusion and the menu interaction is typical for many phones.

Remote Clear – This interaction de-selects any currently selected tags remotely. Incorporating remote interactions into the prototype reduces arm fatigue, which could build with prolonged use with pointing interactions.

C. *The Application*

The prototype application is a tourist guide (shown in Fig. 3) that could be installed, for example, in a tourist office, airport or train/bus station. A Google map of the area allows the user to perform zooming and panning operations by touching the map. For example, when the joystick button is pressed up and the display is touched at a given location, the map zooms into that location. Pressing another key and touching the map, the user is able to pan the map up, down, left and right. Using the application, the user is 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. The itinerary can be either displayed on the screen of the mobile phone itself or on the public screen in greater detail. There are currently three types of markers – restaurants, hotels and events.

Figure 3: Touch & interact used in a tourist guide

The side menu can be switched on or off by pressing a mobile phone button; the menu supports the following features:

- A map key is displayed on the phone when the option is hovered and indicates what each marker icon represents.
- Another option toggles view mode on and off. In this mode, the phone assignments change for viewing and panning the map. A satellite display also appears on the phone to show the user's position (in cases where they are zoomed in).
- A further option toggles to satellite imagery on or off.
- An itinerary option allows users to either drop markers into the itinerary or view the itinerary on the phone/large display.
- The final menu option allows the markers to be filtered by category; for example, filtered to show only restaurants.
- When a tag that contains 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 context menu corresponding to the marker. 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 markers, the markers are also selected. When markers are selected, their names are displayed as a list on the phone display. Moreover, the phone vibrates to indicate that the user has picked up the markers onto the phone.

Integrating a Google map into the application shows the adaptability of the touch & interact technique whilst significantly furthering the functionality of the tourist guide application. To integrate the Google map, an open source project GMap-Viewer [21] was modified. The modifications customized the Google map and markers to suit the tourist application. Hotel, restaurant and event markers extended the abstract markers with additional information. The GMap-Viewer project was also modified in relation to user input as it was originally designed for desktop use. To adapt the package for use with the tag interactions, all the mouse event-functionality was removed and tag interactions were mapped to map controls. For applications in which the source could not be modified, the tag interactions could also be mapped to mouse interactions using a Java Robot API [19]. The server display interface, which contains the map, was implemented using the Piccolo library [20]. This package has a higher level set of API's than the Java 2D Graphics package, making it easier to manage multilayered graphics. The ability to easily layer different parts of the display meant that layers could be painted individually and consequently, saving processing resources.

D. *Tag Granularity*

The input space of the current implementation of touch & interact has a relatively low resolution of 10x10 pixels. The resolution of the projected display, on the other hand, is much higher at 568x576 pixels. Touch screens are an example of a technology supporting a finer input resolution when compared with the current implementation of our approach. However, in reality, most touch screen interfaces in the public sector have targets greater than 2.6 square cm, (independent from the resolution supported by the hardware) [8].

During the development of the current version we considered several solutions that can be used to address this issue. The chosen approach was to enlarge a tag into nine tags. This approach increases the resolution of the tags and normal tag interaction can be adopted in the enlarged area. When a tag with multiple markers is selected, the enlarged area appears that is offset in a direction where it will be displayed within the bounds of the display.

Another approach would be to iterate over the markers within a tag using repeated pressing of a phone key. If multiple markers remain within a single tag once enlarged, this method could be applied. The advantage of this method is that very close markers can be selected. The only downfall to this approach is if there are many markers in a single tag, the iterations would be time consuming in a worst-case scenario. An extension of the iteration approach would be to display a list of the markers contained in a single tag on the phone. This could be a checkbox list so the user can tick the markers they wish to select. The advantage of a list is that the user can iterate from the beginning or skip to the end, which makes selection quicker than the previous iteration method in a worst-case scenario. A further approach is to assign each marker a number, one of which the user can select by pressing the corresponding number on the phone's keypad. Moreover, the phone's joystick could also be used to control a curser indirectly. One more solution is the usage of touch-based gestures. A diagonal gesture upwards, towards the marker will select the bottom half of the tag where the marker is located.

IV. STUDY AND FINDINGS

A preliminary study was conducted following the tourist guide prototype [26]. Two further user studies [25] were conducted in order to investigate how touch & interact compared against existing public display interaction techniques. A description of the studies follows.

A. *A Preliminary Study*

This user study was aimed at discovering the usability of the interactions and feedback techniques using the tourist guide application. It also studied the potential for the interaction techniques in a rich application.

A group of ten subjects were chosen to take part in a within-groups, cooperative evaluation. Each subject 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 complex task using the prototype. The next trial requested the user to select a number of markers, which could be executed with a number of interactions, and identified their preference for particular interactions.

The user study was predominantly qualitative and comprised mainly of observations and subject feedback comments. The main usability problems occurred during hovering interactions. Some of the subjects held the phone too high as they did not know NFC reader was near the tip of the phone. As a result, the adjacent tag above was selected. Also, because a flip phone was used, in some cases, the phone would fold in if it touched the display with too much force. It also became apparent that the phone display was displaying too detailed information. Users reaching to a far area would not be able to read small font on the display. Therefore, the display should be used more effectively using large icons and concise text. When participants used touch & interact in the target selection study, observations revealed that several were inclined to point the phone specifically at the small target rather than the containing tag; this occasionally resulted in the phone reading an adjacent tag.

Each subject started hesitantly, but quickly reached an autonomous and comfortable level. Many subjects enjoyed tentative interactions, such as hovering markers and the contextual help provided. Subjects also liked the fact that the main display could be kept clear using concepts like the disappearing side menu. Furthermore, subjects were pleased with the effect of the haptic and audio feedback to validate actions, such as closing the application and selections. Table I shows the preliminary tag selection times that were recorded to compare the ideal selection speed and the selection speed supported by the prototype. Two types of interactions were tested – pointing to each corner of the display and scrolling down ten vertical tags. Results showed the prototype could not support ideal scrolling times; however, pointing interactions can be easily supported. The polygon-select interaction takes advantage of this fact and is considerably more usable than the equivalent lasso interaction. The time taken for the user to move their arm between tags draws the user's attention away from the short delays in tag reading response. Moreover, as the user brings the phone down onto the tag, the phone will detect the tag a few centimetres before it hits the display. This makes the response time appear reduced. Subject responses to the effectiveness of the different types of feedback were positive. On an interval scale between one and five (very ineffective – very effective), the public display mean effectiveness was 4.1, the phone display was 3.6, and the audio and haptic was 4.0.

TABLE I. MEAN USER STUDY TIMINGS (IN SECONDS)

Scroll (ideal)	Scroll (actual)	Corner (ideal)	Corner (actual)
4.17	8.89	4.12	3.93

B. Target Selection Study

The first user study focused on the comparative performance of touch & interact with regards to target selection. This study was loosely based on the ISO 9241 part 9 Fitt's Law 2D tapping test. 12 participants from varying disciplines were asked to select 30 targets in a sequence of pseudo-random locations on the display. 3 interaction techniques were used to select the targets, which consisted of: finger interaction (using a touch screen), remote interaction (using the phone's joystick to move a cursor via Bluetooth [17]), and touch & interact. Independent variables consisted of the aforementioned 3 *interaction techniques*, 2 *target sizes* (large: 50mm^2 and small: 16.7mm^2), and 2 *target distances* (short: 100mm and long: 345mm). Small target sizes required an additional interaction for selection using touch & interact; the target was split into 9 sections which were mapped to the phone's keypad numbers. Dependant variables were *target selection time* and *error rate* (errors represented missed target selections, and incorrect keypad number selections with touch & interact and small target sizes).

The results for the study show that finger interaction performed best, touch & interact is the intermediate and remote interaction performed worst in all trials. Overall, a 3-way repeated measures ANOVA shows the differences with interaction technique are significant (Greenhouse-Geisser) ($F_{1.07,11.74} = 172.13$, $p < .001$). The ordering of respective interaction techniques in terms of performance was expected, but the primary goal was to analyse where touch & interact fits between the two alternatives. Touch & interact is a great deal closer to finger interaction performance (41% slower) than remote interaction performance (135% faster). Assuming the likely event that only large targets sizes (NFC tag size) are only used in an application, touch & interact is only 300ms slower (27%) than finger selection.

C. The Picture Board Study

The second study focused on the usability aspects of touch & interact. A picture board prototype (Fig. 4) was created which enabled 12 participants to search for, and drop, 6 randomly selected pictures from the phone to the board. In addition, users were required to pick 6 pictures from the board to the phone.

The study was carried out by participants individually. Users were required to select a picture from a list on the phone (Fig. 4 left). Once selected, participants could drop the picture by either doubling-tapping on a blank area on the board (Fig. 4 right) – with finger selection – or reading a tag in a blank area and confirming with a soft-key press – using touch & interact. Identical interactions with pictures (rather than blank areas) would pick them onto the phone.

Only two interaction techniques were tested: touch & interact and finger selection. This is due to remote selection's poor performance during the prior study. A variation of the Ease of Use survey instrument elicited participants' feedback on the usability of the respective techniques. The results of the survey show better results for touch & interact, especially for overall ease of use, intuitiveness and enjoyment. When participants were asked to rank the interaction techniques, there was evident participant preference in favour of touch & interact (8 vs. 4).

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 this is the case when the user has to mediate between both the phone and large screen. Moreover, this is further impacted by large context switches between the phone and screen with the touch-screen method.

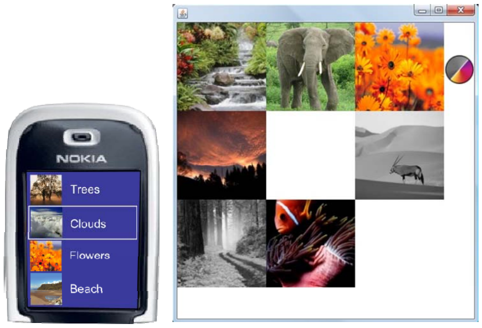

Figure 4: (Left) List of pictures on the phone, (right) the picture board

V. CONCLUSION

This paper presented: the touch & interact interaction technique; its architecture; a first implementation; a tourist guide prototype; and three studies focused on feasibility, performance and usability. Using touch & interact, a user is able to interact with a potentially large screen by touching it with their mobile device. This system provides a solution to overcome the limited output capabilities of mobile devices through the usage of the large display and the mobile phone in parallel. By using a large dynamic display in the interaction, spatial-awareness is provided for applications that require it. Furthermore, as the display is dynamic, the only reliance on the phone is when displaying sensitive/private information. Yet, the phone's display can also be used to show complementary "magic lens" information. It is important to make use of the features provided by the phone (e.g. various feedback, input modalities, storage, connectivity, etc.) as this is where many of the advantages of the interaction come from.

The tourist guide prototype has also uncovered some important general points to be considered for future development. For example, pointing interactions work much better than scroll interactions. This is due to the fact that the response time lag is observable with scrolling. In addition, careful consideration must be made to how the phone display is used in the interactions. Information on the phone display must be eye-catching and viewable from arm's length. If too much information is displayed on the phone's display, it will simply be ignored.

To summarize the results of the studies conducted [25], touch & interact yielded performance results much closer to touch screen interaction than remote interaction. Touch & interact has also shown the best results regarding usability comparisons with a touch screen alternative, within in the context of the study. The project has also uncovered necessity for multiple tag reading and experimentation with finer granularity tag matrices, using smaller tags [16]. These improvements will provide finer resolution for input and faster tag response times.

VI. ACKNOWLEDGEMENT

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