# Projector Phone: A Study of Using Mobile Phones with Integrated Projector for Interaction with Maps

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## ABSTRACT
First working prototypes of mobile phones with integrated pico projectors have already been demonstrated and it is expected that such projector phones will be sold within the next three years. Applications that require interaction with large amounts of information will benefit from the large projection and its high resolution. This paper analyses the advantages and disadvantages of an integrated projector when interacting with maps, and discusses findings useful for the development of mobile applications for projector phones. We report in particular the implementation of an application that uses either the screen of the mobile phone, the projection or a combination of both. These three options were compared in a user study in which the participants had to perform three different tasks with each option. The results provide clear evidence for the positive aspects of using a built-in projector, but also show some negative aspects related to text input.

## Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Input devices and strategies; Prototyping.* H.1.2 [**Models and Principles**]: User/Machine Systems – *Human Factors.*

## General Terms
Measurement, Design, Experimentation, Human Factors.

## Keywords
Projector phone, experimental comparison, interaction design, map interaction.

## 1. INTRODUCTION
Mobile phones are the first truly pervasive interaction devices that are currently used for a huge variety of services and applications. When used for interactions involving large amounts of information, a key limitation is the small screen size [1]. Typical examples include interaction with maps; managing, searching and watching pictures and videos; browsing web pages and reading large documents. Optimization of user interfaces for such applications has been the focus of many research projects in previous years such as [2, 3].


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Huge interest has been expressed over the last few years in both wearable and integration of projectors into mobile devices. Texas instruments, Motorola, 3M and Nokia for example have been working on embedding pico projectors into mobile devices and predict that within three years consumers shall see these devices emerging in the market. The presentation of a full working prototype of a mock mobile phone with a built-in projector was unveiled at CES 2008 [4]. Remarkably, it was the same size as the iPhone.

Such projector phones will improve the usage of many applications and will lead to new interaction techniques. The projected display has the advantages of a larger size and potentially higher resolution when compared to the typical small screen of the mobile phone. However, there are still many open questions with regards to the effects imposed on the battery life of the mobile device. Secondly, the brightness of the embedded projector when compared to currently available projectors is also a concern.

This paper focuses on the usage of mobile phones with built-in projectors for interacting with map applications or location based services such as Google Maps, i-area [5] or TomTom for mobile devices [6]. At present using such applications on current mobile phones requires many zooming and scrolling interactions, leading to relatively high task completion times, a high mental demand and a high frustration level.

A study was performed to analyze the advantages and disadvantages of using a projector in this context. The study also explored whether the mobile phone screen should be switched off when using the projector or whether it is better to use both displays in parallel. The issue of task-dependant visualization was also analyzed; for example, it was assumed that text entry should be done without using the projector and specifically using the mobile phone screen. It was assumed that the visualization of the projected map is the preferred and best solution. The results of our study clearly show the advantages of using an embedded projector when comparing it with the screen of a conventional mobile phone.

The paper is organized as follows. The next section relates our work to existing approaches, and focuses in particular on related work regarding mobile phones with integrated pico projectors. Following this, the hardware that was used to emulate the mobile phone with a built-in projector is described when considering that these devices are currently not available. The design of our study and the different tasks which were performed by the participants when using the three different interaction techniques, phone-only, projection-only and a combination of the two are then discussed. We then discuss the qualitative and quantitative results of our study and their implications.

## 2. BACKGROUND

Many research projects, applications and products have focused on different ways to overcome the limited screen size of mobile devices. Typical application areas in which this is an important problem are watching pictures and videos, navigating maps and reading web pages, documents and emails.

One typical approach is to zoom in and scroll to see the information in a more detailed view and to zoom out again in order to return to a context view. Chittaro, for instance, discusses that classic desktop solutions used to overcome the limited size of the screen, such as overview & detail (two screens, one for overview and one for detail) and focus & context (e.g. fish-eye view) cannot be used on mobile devices in an efficient way [7]. Many corresponding solutions have been presented in the last few years, however, most of them improve the applications but the usability and speed often falls short when comparing them with the usability of desktop computers or laptops. Examples include the Halo interaction technique that provides an indication of the existence and distance of points of interest that are not shown on the display [2]. Another approach to overcome the limited screen size is the interaction with big screens, as done in the Hermes Photo Display [8] and SharedNotes [9].

Pioneering work on the usage of handheld projectors has been undertaken by Mitsubishi Electric Research Labs and the University of Toronto [10-12]. Raskar et al. were among the first who introduced the term handheld projector following the trend of projectors becoming cheaper, smaller and capable of battery operation [10]. This paper presents in particular an approach that allows the projection of information onto non-planar surface. Through this, it is possible to project a non-distorted image on any kind of surfaces from any kind of angle. Beardsley at al. discuss different ways how to interact with such a handheld projector, how to control a cursor within a projection and application areas like the projection of a web page and augmentation of a fuse box with additional information [11]. Cao at al. continued this work and presented in particular, multi-user interactions and applications, such as exchanging music and image files between two users, collaboration on a document or exchanging contact information [12]. In addition to this, they also present a single user scenario that involves the usage of the projection as a magic lens when interacting with a map. Although all this previous research [10-12] could be used by mobile phones or PDAs with built-in projectors, none explicitly focuses on these devices and their input capabilities such as keypad and joystick. Furthermore, they did not evaluate how these projectors can improve existing applications running on mobile phones and how they may have to be adapted for this new hardware.

One key technology that allows the development of very small projectors is DLP (Digital Micromirror Device), invented by Texas Instruments in 1987 [13]. This approach involves representing each pixel by a repositionable microscopic mirror. At present it is possible to buy palm-sized handheld projectors using this technology, for example, the Samsung SP-P310ME (12.7 x 9.5 x 5.1cm). Powering this projector using the attached battery also makes the projector extremely mobile for a period of 2 – 3 hours. Recently, Texas Instruments showed a full working prototype of a mock mobile phone with an integrated projector which was the size of the iPhone at CES 2008 [4]. A spokesman of the company announced that these devices could be on the market in 2010.

In addition to this, 3M [14], Microvision in cooperation with Motorola [15, 16], explay (explay.co.il) and digislide (digislide.com.au) are also developing small projectors that can be used in combination with or can be embedded into mobile devices. Furthermore, some of these companies announced that such products will be available in 2010 or earlier [4, 16]. Tero Ojanperä, Nokia's chief technology officer also predicts projector phones and the likelihood that they will be available as soon as 2010 [17]. All of the above statements show the reality that it shall soon be possible to purchase mobile phones with built-in projectors or pico projectors that can be coupled with a mobile device. However, it will take some time, probably comparable to the situation when the first camera phones hit the market, until problems like battery consumption and brightness are solved. But having such displays opens up the opportunity to improve heavily the usage of current applications and to develop new ones that benefit from projection.

## 3. HARDWARE USED

The following hardware was used to compare the three different interaction techniques which use either the mobile phone screen, the projection or a combination of both.

**Mobile phone display only**

A Nokia N95 was used with a display resolution of 240 x 320 pixels, an aspect ratio of 3:4, portrait format and a screen size of 4.0 x 5.4 cm. A mobile phone with such a high resolution and big display was used to address the fact that it is more and more common for people to use and buy mobile phones with these properties. The keypad and the joystick were used to control the applications.

**Projection-only**

A Nokia N95 was attached to the Samsung SP-P310ME, a battery powered handheld projector that was used to emulate a mobile phone with an integrated projector. The projector has a size of 12.7 x 9.5 x 5.1cm (w x d x h) and a resolution of 1024 x 768 pixels. The prototypes use just part of this resolution, 528 x 704 pixels, to have the same aspect ratio as the N95 and also to simulate the portrait format of the mobile phone.

Figure 1 illustrates the experimental setup. Although the projector weights merely 700 grams (without the battery) and the Nokia N95 only 120 grams, the phone was attached to the projector with it hanging from a frame with pieces of elastic.

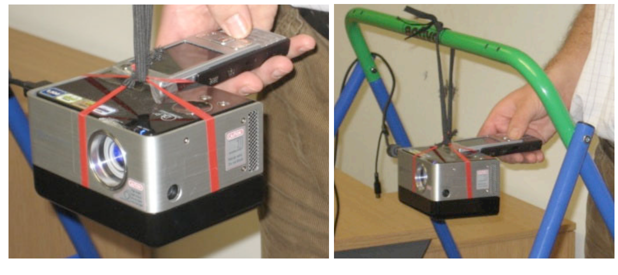


**Figure 1. N95 attached to the handheld projector to simulate real use in the experiment.**

The reason for this is as follows, each participant had to use this prototype for about 30 minutes and it was assumed that the resulting arm fatigue would negatively influence the results of the study. Also attaching the phone-projector combination to a frame represented a more realistic setting. It was recognized in our study that the projection waggled when the user interacted with the mobile phone. This is a realistic effect and would happen when using a phone with an integrated projector in the near future.

The user stood 1.8 meters away from a wall resulting in a projection of size of 41 x 55 cm. The screen of the mobile phone was covered in order to test the projection-only version, this then provided the user with a standard keypad and joystick for input.

**Mobile phone display and projection**

For this setting the same hardware as in the projection-only version was used. However, the screen of the mobile device was not covered. Figure 2 shows the difference between the mobile and projected display with respect to the size and resolution of their screens. The projected screen area in terms of pixels is approximately 384% larger than the available display area on the mobile phone and the horizontal and vertical resolution more than doubles.

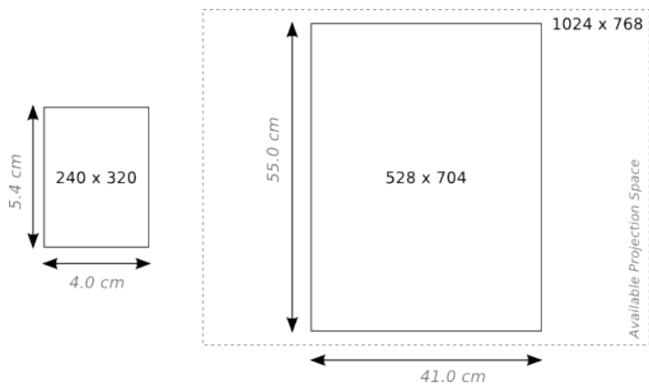
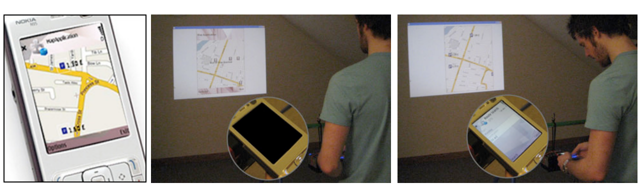



**Figure 2. Comparison of the display size and resolution of mobile phone screen (left) and projection (right).**

A map application was implemented in order to compare the three interaction techniques: phone screen only, projection-only and the combination of both (Figure 3). Already Rohs et. al. have used mobile map navigation with mobile devices to compare the performance of three different mobile interaction techniques [20]. A similar approach was used by Reilly et al [21]. To tie in with these two approaches, we decided to use map navigation to compare the three different interaction techniques, allowing us to observe the advantages and disadvantages of each of them.



a b c

**Figure 3. Prototypes for a - phone-only, b - projection-only, c - combination of phone display and projection.**

For each prototype the same map was used - a city map of Manchester taken from Google maps. To get a clear and detailed view of the map, the highest available zoom level was used, at this level all streets could be seen easily. As the mobile phone has the smallest display, only 175m in width and 250m in height of the actual map was visible giving a total area of 43750m². The projection-only interaction technique showed 370m in width and 360m in height of the city map, resulting in 133200m² of map area. For the combination of phone and projection more of the map was visible, 370m in width and 487m in height, resulting in a total area of 180190m².

# 4. IMPLEMENTATION

**Mobile phone display only**

Java ME (MIDP 2.0, CLDC 1.1) was used to implement the application for the phone-only version in which the user was able to scroll the map, move the cursor and to display car parks, sights or restaurants on the map. Text input was also supported, e.g. for selecting the start and end point of a route.

**Projection-only**

The N95 provides a TV-Out interface and using this it is possible to connect the N95 directly to the projector. However, the mobile phone is not able to accommodate and take advantage of the full resolution of the projector, and thus, the displayed resolution corresponds to that of the mobile phone screen (240 x 320 pixels). For this reason the prototype was implemented using Java SE and deployed on a laptop computer with the projector connected to it. This approach allowed us to take advantage of the higher resolution of the projector; we would expect a similar resolution of projectors embedded in mobile phones. A Bluetooth communication channel was maintained between the mobile phone and laptop to facilitate the sending of control messages. Key presses and joystick movements representing scrolling, cursor movements and selection actions were used to control the application remotely. Title and menu bars were added to the projection at the top and the bottom respectively, giving the illusion to the user that the mobile phone interface is actually projected. In this setting the mobile phone screen was not used and thus covered.

**Projection and mobile phone screen**

The last prototype was implemented using Java SE and Java ME. The phone displayed all the navigation menus and text input to the user with the projection displaying the map. As with the previous prototype, scrolling the map, cursor movement and selection actions were controlled by the mobile phone.

# 5. EXPERIMENTAL DESIGN

The experiment was a repeated measures within-participant factorial design 3 x 3 (interaction techniques x tasks). The independent variables were *interaction technique* with three levels (phone-only, projection-only, projection and display) and *tasks* with three levels ("Find the cheapest car park", "Select sights to visit", "Find a restaurant"). The factorial design produced 9 different trials per user. The following hypotheses were specified.

- (H1) Task completion time of phone-only is higher than the interaction techniques that use a projection.
- (H2) Participants spend less time scrolling when using a projection of the map.
- (H3) Typing text using projector-only takes more time than when making text input on a mobile phone.
- (H4) User satisfaction of the interaction techniques that use a projection is higher than the phone-only version.
- (H5) User satisfaction of the interaction technique projection-only is lower than the one for the combination of phone screen and projection.

- (H6) The usage of the interaction technique projection-only is more intuitive and easier to learn than the combination of phone screen and projector.

# 6. PROCEDURE AND TASKS

14 participants, 8 males and 6 females, took part in the experiment. 10 of which were students at Lancaster University. 1 participant was a professor and 1 was a high school student, the remaining 2 participants were departmental administrators at the university. Participants were aged between 13 and 41 with a mean of 25.6 years. All participants owned a mobile phone and 4 had previous experience using map applications on mobile phones. The participants rated their experience with computers and mobile phones from none to expert with mean values of 4.0 and 3.21 respectively (5 = expert, 1 = none).

Participants took part in the experiment individually. At the beginning of the experiment the key functions with regards to interaction with the map were explained. The mobile phone's joystick allows the user to scroll the map in either a left or right and up or down directions. Keys 2,4,6,8 mimicked the same functionality as the joystick, however they controlled the on-screen cursor. The select button located at the center of the joystick or key 5 allowed participants to perform select or deselect operations on the map.

For each interaction technique (phone-only, projection-only and combination of both) each participant had to complete a total of three tasks. Interaction technique and task order were counterbalanced to avoid learning effects to prevent influence of the results.

Following the completion of each interaction technique, a post task interview occurred requiring each participant to answer a series of subjective questions. These questions were taken from the IBM Computer Usability Satisfaction Questionnaire [18] and the NASA Task Load Index [19]. Following completion of all three interaction techniques, a post experiment interview occurred with each participant.

Each participant was filmed with a camera during the experiment in order to record the number of context switches that occurred during the usage of the projector based interaction techniques.

## 6.1 Task 1: Find the cheapest car park!

For this scenario the map displayed a total of 10 car parks. Car par icons displaying hourly rates were randomly placed on a map of Manchester city center as shown by Figure 4a.

Each participant had to find the cheapest one. A different set of randomly generated car park locations and prices were used with each participant. The cheapest car park rate varied between £0.50 and £0.80 and was assigned just once with other rates appearing more often. Following each selection, participants were informed whether they were successful (Figure 4b) or unsuccessful (Figure 4c). In case of failure they had to retry until they had found the correct car park icon.

As the combination of mobile phone and projection provide two screens to display content, we decided for this task to use the projection to display the map, whereas the mobile phone's display contained the title and menu bar.

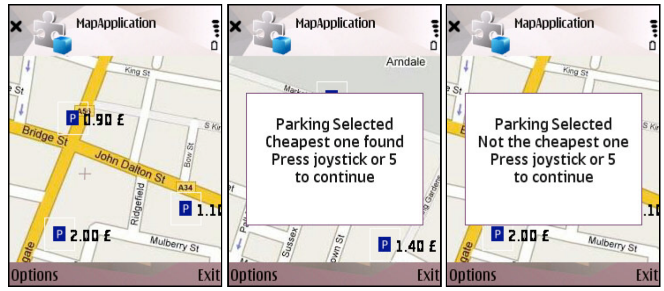



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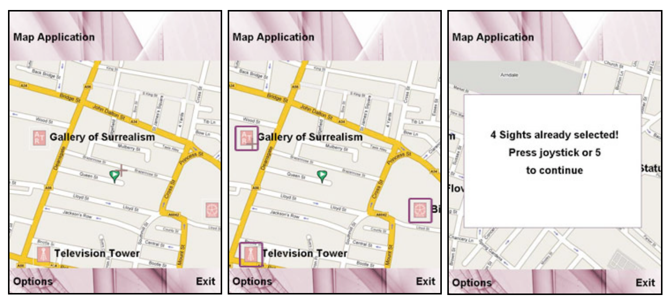
**Figure 4. Screenshots of task 1 as displayed by the phone: a - car parks on map, b - success pop up, c - failure pop up.**

## 6.2 Task 2: Select sights to visit!

In this scenario a predefined location surrounded by eleven different sights was displayed on the map (Figure 5a). Each participant had to select four given sights in the order they would visit them. When a participant selected an icon, a purple border appeared around that icon to emphasize the selection (Figure 5b), with the border disappearing in the case of de-selection. Three different configurations of start point and sights were used to avoid any learning effects, with the given location representing both the start and end point. The participants were limited to select a total of 4 sights with a notification shown if they tried to exceed this (Figure 5c). Participants were responsible for stopping the task once they had believed they had finished. It was not necessary to notify the participants of success or failures, as there were several possibilities to find an appropriate order.



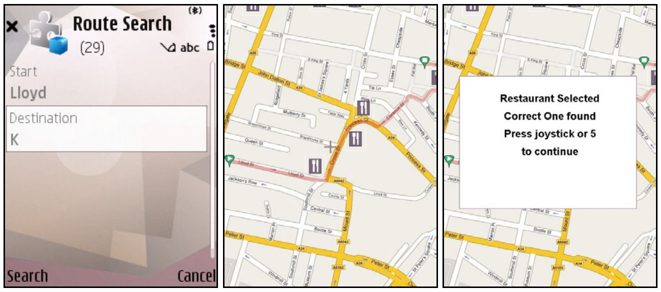

a b c

**Figure 5. Screenshots of task 2 as displayed by the projector: a -start point, b - selected sights, c – selection limit notification.**

Similar to the first task it was decided to show the map on the projection, the mobile phone contained the title and menu bar.

## 6.3 Task 3: Find a restaurant!

For this task, a route with a start and destination point had to be typed in by the user (Figure 6a), this was then displayed on the map and along this route several restaurant icons were placed (Figure 6b). The participants had to find and select the restaurant icon that could be found in the center of the route, again participants were informed whether they succeeded (Figure 6c) or failed. In case of failure they had to retry until the correct restaurant icon was selected.




a b c

**Figure 6. Screenshots of task 3 as displayed by the phone-projection combination: a - form on the phone, b - projected route, c - correctly selected icon.**

For the combination of mobile phone screen and projection, the mobile phone's display provided a form containing two text fields for the input of start and destination point while the projection displayed the map.

## 6.4 Dependent measures

The dependent variables were task completion time, scrolling time and error rate. For the first two tasks (*Find the cheapest car park!* and *Select sights to visit!*), the task completion time was the elapsed time from the user pressing the left soft button of the mobile phone and ended with the selection of the correct icon(s) on the map. For the third task (*Find a restaurant!*), the task completion time was the total time elapsed starting from the first text input and ended with the selection of the correct icon on the map. The task completion time for the third task was split into two parts, time for map navigation and time for text input.

Scrolling time was measured through every single key press on the mobile phone for scrolling the map or moving the cursor.

Errors were differentiated into two types, selection errors and typing errors. Selection errors were counted when the participant selected the wrong icon(s). Typing errors are all errors that occurred during text input.

# 7. RESULTS

## 7.1 Timings and Errors

Figure 7 shows the average task completion times for the different tasks and interaction techniques. For tasks 1 and 2 the projector based interaction techniques clearly outperforms the mobile phone screen only version in terms of task completion time. These results verify (H1).

For task 3 the mobile phone screen only version is the fastest and performs better than the two interaction techniques that use projection. In order to analyze this in more detail, the overall task completion time for task 3 was split into two parts - time for navigation on the map and time needed for text input. As Figure 7 and 8 clearly show, the interaction technique with projection-only is faster than the phone-only version when considering the task completion time without time for text input. This is thoroughly reasonable, as on the one hand a bigger screen facilitates the navigation on a map, but on the other hand it is much more difficult to type text using the mobile phone while looking up at the projection.

Nevertheless, the combination of mobile phone and projection is still slightly slower than the phone-only, even if the time for text input is excluded. This can be traced back to the fact that for the combination of projection and phone different contents were shown on projection and mobile phone. However, participants expected to see the same content on their phones and were thus distracted by the different screen on the phone which resulted in slower task completion time.

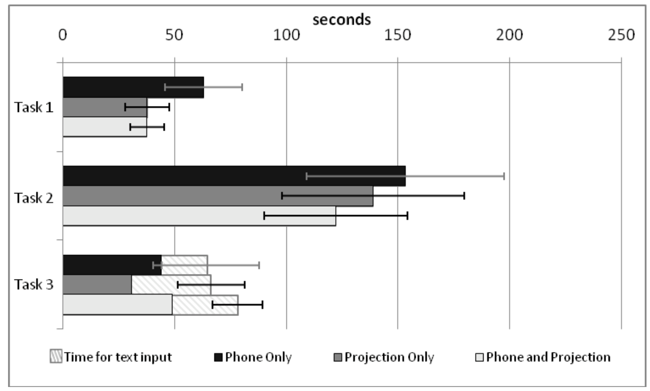



**Figure 7. Average task completion time.**

Altogether, both techniques with projector show on average a better task completion time than the mobile phone. When combining the task completion time for each of the three tasks, the mobile phone-only version needs 280.8 (seconds) (M = 93.7, SE = 11.18), while the interaction techniques with projection are faster with 243.0 for the projection-only (M = 80.1, SE = 10.1) and 238.2 for the combination of phone screen and projection (M = 79.4, SE = 9.6). These results confirm (H1) to be true. When comparing phone-only and projection-only, and phone-only and the combination of phone and projection, the results show that the combination of projection and phone method is approximately 15.3% faster than the phone-only technique. The projection-only is still 13.5% faster than the mobile phone only technique.

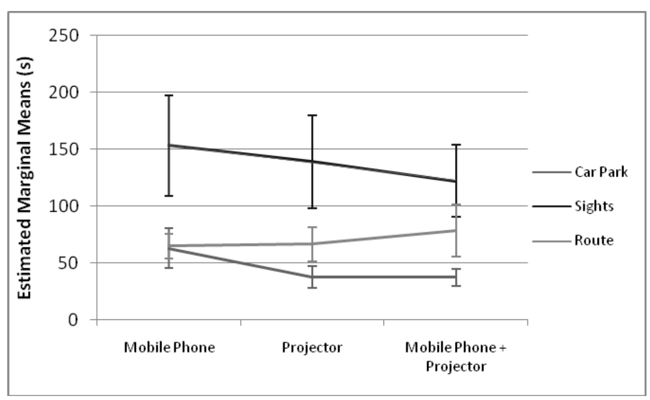



**Figure 8. Estimated Marginal Means – Task completion time.**

The results clearly show that the mean time the participants needed for text input when using projection was longer. The fastest text input was made with the mobile phone-only (M = 20.71, SE = 1.8) followed by the phone-projection combination (M=29.3, SE = 5.9). The projection-only version is the slowest interaction technique in terms of text input (M = 35.46 SE = 5.5) which proves (H3) to be true.

In addition to task completion time, scrolling time was analyzed (Figure 9). In this case the projector based interaction techniques have produced much better results as expected when compared to the mobile phone screen only version and hence prove (H2) to be true. The mobile phone screen only has the highest scrolling time (M = 44.5; SE = 7.1) for all tasks. When comparing the projection-only and the phone and projection combination, the results indicate that both techniques are very similar. Considering the overall scrolling time, the mobile phone and projector combination is slightly faster (M = 33.6, SE = 3.8) than the projector-only technique (M = 33.8, SE = 5.0).

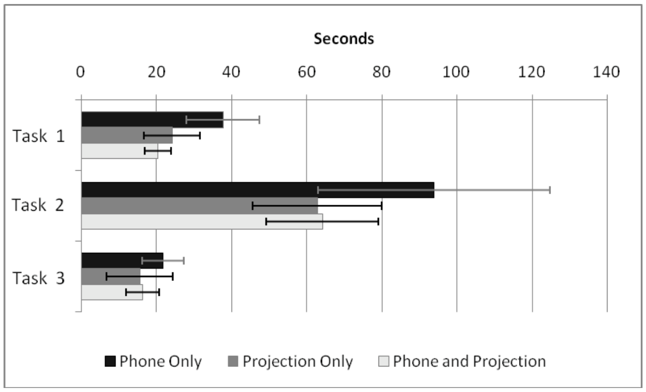



**Figure 9. Average scrolling times.**

The number of errors was also recorded, this included the wrong selection of a car park, sight or restaurant; not completing the task; wrong order of selection for sights and text input errors (Figure 10).

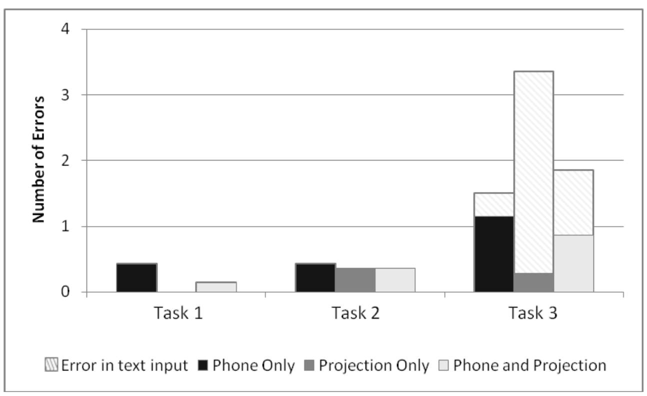



**Figure 10. Average error rates of the different tasks.**

Regarding the number of errors that occurred during the tasks, it can be stated that for tasks 1 and 2 the majority of errors were caused by the mobile phone screen only version. Fewer errors were made when using the projector interaction techniques.

For the first task not even one error occurred during the usage of the projection-only method, for the combination of phone and projection a mean of 0.36 errors occurred. However, the interaction techniques using projection show worse results for the third task.

But by differentiating between input errors and selection errors, the results also indicate that without the text input the projector interaction techniques outperform the mobile phone. Regarding the error quantity during the text input (H3) is proven to be true.

## 7.2 Context switches

During the experiment the amount of context switches for the interaction techniques using projection were counted. A context switch was defined as occurring when the users view switched from the mobile phone to the projection or vice versa, with each counting as 1 context switch. The interaction technique with projection-only requires a higher number of switches in terms of text input (M = 25.3, SE = 4.6). The combination of phone and projection required almost no context switch (M = 0.67, SE = 0.376) as the text input was performed using the mobile phone. The text input using the projection-only method requires more context switches as it was not possible for the participants to focus on either phone or projection, as the interaction with the mobile phone keys were necessary as well as the look on the projection to check the input. With regards to the number of context switches made during map navigation, the projection-only shows a higher amount of context switches (M = 10,17, SE = 2.2) for the first task when compared with the combination of phone and projection (M = 8,59, SE = 1.1).The phone-projector combination requires more context switches for task two (M = 33.83, SE = 4.1) and three (M = 9.83, SE = 2.1), excluding the amount of switches for the text input. The projection-only interaction technique requires less context switches (M = 32.58, SE = 5.5) and (M = 6.75, SE = 1.8) for task 2 and 3 respectively. Nevertheless, the difference regarding the amount of context switches between the two compared interaction techniques is rather low. From these results it can be concluded that the number of context switches during the navigation on the map is not necessarily connected to the interaction technique (projection-only and combination of phone and projection), but is rather dependent on the amount of key changes on the mobile phone as the results of the three tasks indicate.

## 7.3 User feedback

After each interaction technique, the participants had to express their agreement to several statements of the IBM Computer Usability Satisfaction Questionnaire [18]. The questions were represented using a 5 point likert scale from strongly agree to strongly disagree. Figure 11 presents a summary of the results.

In general, the interaction techniques using projection gained better results than the mobile phone-only. The participants felt that it was easier to use the projection interaction techniques than the mobile phone. As a result the participants were able to complete the tasks quicker when compared to the mobile phone, and in addition felt more comfortable when using the projector.

Most participants agreed that in all three interaction techniques the mobile phone screen only version was the easiest one to learn, although the methods using projection also received very high agreement.

The projected interface appealed to the majority of participants resulting in a more enjoyable interaction. Participants commented that the interaction felt more intuitive using the projection-only and thus prove (H6) to be true. The participants found the combination of phone and projection less intuitive when presented with two screens containing different content.

Regarding the speed of the interaction and the interaction difficulty, the majority of participants found using the projection faster and easier.

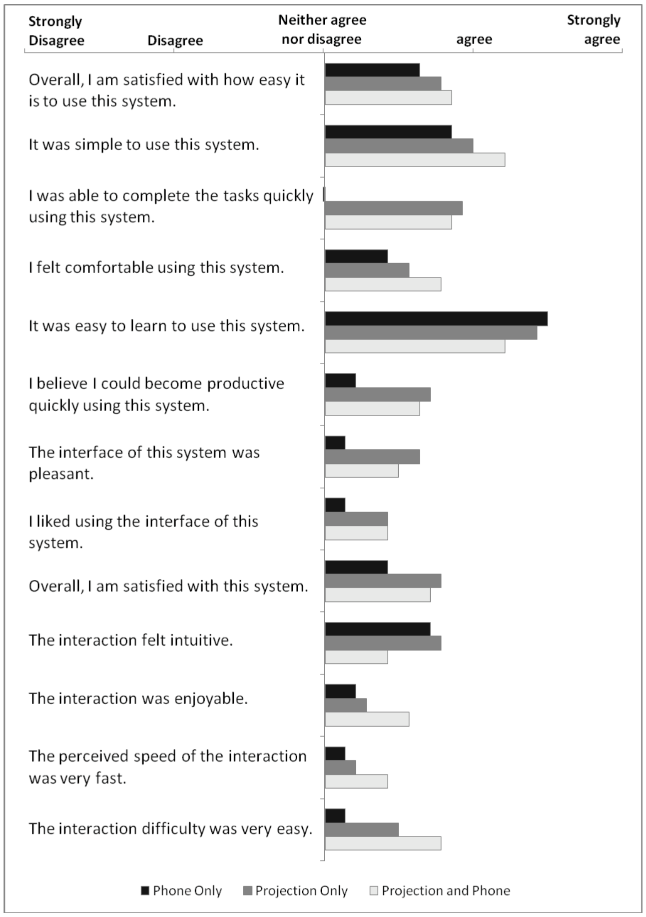



**Figure 11. Average user feedback regarding the interaction techniques.**

It is evident from the results that there is a general distinct difference when comparing both projection interactions to that of the mobile phone. However, when comparing the projection interactions individually the distinction is not as clear. The interaction technique combining phone and projection gained higher agreement concerning the ease of use. In contrast to this, most participants felt that they were able to complete the task quicker with the projection-only interaction. A possible reason for this is that the interaction felt more intuitive as discussed above. But nevertheless, in terms of enjoyment the majority of users preferred the combination of phone and projector. In terms of speed and interaction difficulty, the combination of phone and projection was favored by more who perceived having two displays as a distinct advantage.

It is hence difficult to say which of the two interaction techniques achieved higher agreement. But the satisfaction level probably can be improved by combining the advantages of both interaction techniques to overcome their shortcomings.

In the post task questionnaire the participants were also asked about mental demand, frustration level, perceived performance and needed effort using the NASA Task Load Index [19] (Figure 12). Completing the tasks without a projection required a higher mental demand and resulted in a higher frustration level and lower perceived performance. Also the effort when not using a projector was rather high.

The combination of phone and projection was slightly better than the projection-only with regards to the mental demand, frustration level and effort. Nevertheless, they are very similar in terms of performance.

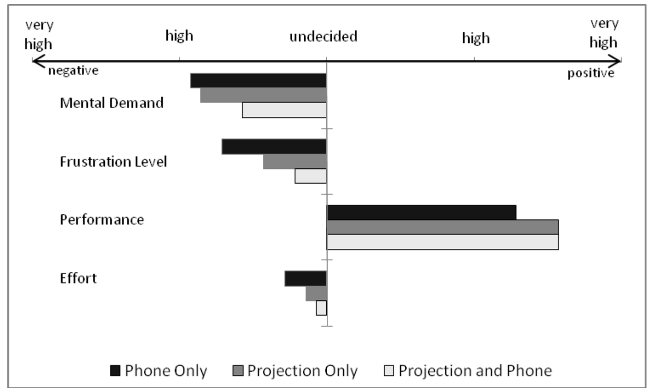



**Figure 12. Average NASA Task Index user feedback regarding the interaction techniques.**

## 7.4 User preferences

At the end of the experiment participants were asked to state their interaction technique order of preference. The results are presented in figure 13 and underline the results from the post task questionnaire. Most participants preferred the combination of phone and projection over projection-only as it facilitates the text input by using both available displays. Furthermore, it offers a larger screen area and allows easier interaction with the map. The second choice was the interaction technique with the projection-only as it has a larger screen area, but a more difficult text input than the combination of phone and projection.

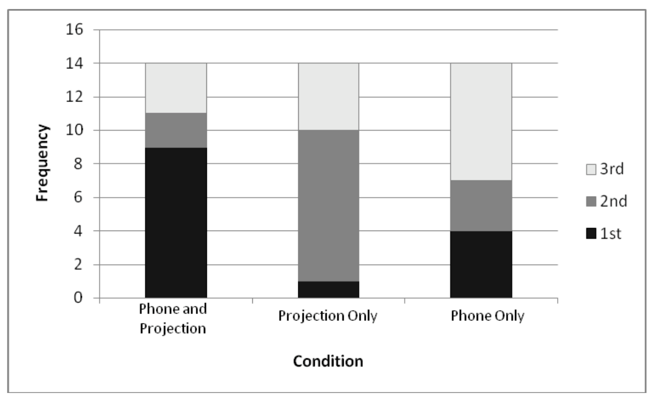



**Figure 13. Ranking of interaction techniques.**

The phone-only seems to be preferred as first place more often than the projection-only. However, it should be mentioned that in this case the mobile phone was also often preferred to the combination of projection and phone. This is due to the familiarity of the mobile phone and its overall intuitiveness. Altogether, the mobile phone is still ranked in third place due to the limited field of view and the lack of overview.

The user's preferences also can be seen in the average marking that was based on the same principle as the ranking. The first rank was marked with one, the second with two and the third with three. As the combination of phone and projector was the most preferred, it achieves an average marking of 1.6, wherein approximately 64% of the participants ranked this interaction technique first place. Both the projection-only and phone-only obtained an average marking of 2.2.

Besides the ranking of their preferences, the participants also had to rank the three interactions in which they believed they were the fastest. The results were similar to their ranking of preference. The mobile phone-only was on last place whereas the projection-only was on second and the combination of both on the first place. The reasons for this were quite similar to the reasons the participants gave for the previous ranking. The phone was claimed as more familiar and intuitive, however, most participants were frustrated by the limited screen size which resulted in a high amount of scrolling. They felt it was much easier to complete the task with the projection-only because of the larger interface. This statement supports (H4). Some participants even stated that they thought they were faster using the projection-only method than the combination of phone and projection because they only had to focus on one screen. But the majority felt they were fastest with the combination of projection and phone due to the possibility of focusing on the mobile phone's display during text input, but still having the larger projection for navigation on the map. This in turn supports (H5).

## 7.5 Qualitative Results

During and at the end of the experiment, qualitative data was gathered. The participants were asked several questions in the post task questionnaire and they had the possibility to give comments between the tasks.

The majority considered the idea of a built-in projector in a mobile phone as an interesting issue and they could also think of many applications such as photo, video or web browsing; viewing maps, timetables or plans; or the usage of such a projector for presentations.

However, the participants were very conscious about what to display using the built-in projector. Most of them would for example, not display very private information like names, phone numbers or text messages in a public environment. Thus, the more private the information the less reluctant they would feel in projecting this information in this context. This is probably also the reason why most participants would only use the projection if there is a place where they have some privacy, for example a table in the train. Participants also commented that they would rather use projection in a group setting as they see more benefits in it.

In the post task questionnaires the participants also had the possibility to state positive and negative aspects of each interaction technique which are discussed in the following.

**Phone-only.**

There were a few positive aspects regarding the mobile phone-only method. In general the participants appreciated the familiarity and intuitive aspects of the mobile phone. Furthermore, some participants stated that the interaction felt faster and more fluid due to the familiarity. Having the mobile phone's keys and its display in front of them was another positive point of the phone.

Many participants commented that the screen size was too small and as a result caused several problems during the usage of the map. The participants could not see enough of the map and as consequence had to do a lot of scrolling. Additionally, it was difficult to find a reference point on the map to get an imaginative overview in their minds. This is the reason why many participants found fault with the lack of the possibility of zooming. Some of them also wanted to have a small overview of the whole map in the left corner of the display.

**Projection-only**

The projection-only technique was criticized in two points. The first one was the difficulty in making text input with the mobile phone's keypads while looking on the projection to see the actual text input, as predicted in (H3). Some participants stated that they were distracted by the jittering projection on the wall. Most of those had used the mobile phone with just one hand which most probably caused the high amount of jittering because most people who used the mobile phone with both hands noted their surprise that the jittering of the projection did not disturb or affect them during the task.

It was also said, that the projection itself was a very positive aspect of this interaction technique. It was easier for the participants to find things on the map due to the larger field of view and hence resulted in higher satisfaction with the interaction techniques with projector which then shows (H4) to be correct.

**Phone and Projection**

As result of the different content that was shown on the projection and phone, some participants got distracted and had difficulties in handling the context switch.

Nevertheless, the majority of the participants said that text input was a very positive aspect of this interaction technique because it was possible to focus on the mobile phone's screen during text input whereas the projected screen could be used for navigation.

There was also the wish to see the same content on the phone also on the projection, so that the projection could be used to get an overview of the map whereas the map on the mobile phone would allow the user to add the 'finishing touches'. Adding this to the prototype would probably also overcome the shortcomings caused by the context switch.

Another positive aspect was the bigger screen available for the map, participants sought benefits in having a larger field of view. Furthermore, the interaction with the projection felt natural and intuitive.

The participants also proposed some suggestions concerning all three prototypes. They would have liked to have a bigger and faster cursor as well as just one control for map and cursor instead of separate navigation methods. Some requested predictive text for the text input. Overall, the prototype for phone and projection was rated positively.

# 8. DISCUSSION AND FINDINGS

The aim of this section is to summarize, analyze and discuss the results of the study and to give guidelines for the future development of applications for mobile phones with built-in projectors.

**Higher Resolution and Display Size**

The results clearly show that the higher resolution and display size improved the task completion time, reduced the time needed for scrolling, leads to a lower error rate and a very positive user feedback. The fact that the projection was not stable as the projector swung to the left/right and up/down influenced these results in a slightly negative way. One question to ask is how good will this issue be solved through the integration of software and hardware based image stabilization approaches.

**Text Input**

Our results show clearly that the mobile phone screen should be used for providing feedback regarding text input. For most users it is very important that they see the keys of the keypad and to see direct feedback of what was typed on the mobile phone screen. Displaying this information on the projection leads to very high and unacceptable switching costs (time, cognitive load).

**Usage of Projection and Mobile Phone Display**

The results show that participants preferred to use both displays when considering simplicity, comfortableness, enjoyment and perceived speed. With this in mind, the use of both displays when developing future applications for mobile phones with built-in projectors should be considered.

A context switch occurs when the user's view shifts from the projection to the mobile phone and vice versa and typically occurs when the user has to check what to type using the keypad on the mobile phone. At this point, the user's focus is no longer directed towards the projection and the current context with regards to the key pressed is lost. This highlights the importance of the mobile phones display in terms of providing and enabling the user to see the current application context. This can be done in a very simple way by just showing the same information on the mobile phone screen as on the projection. However, this is not the optimal solution as the resolution of the projection could potentially be higher than that of the mobile phone display. An intermediate solution has to be found which should be designed, analyzed and evaluated in more detail in future work.

**Applications**

As already expected and confirmed by the feedback of the participants, certain applications have been identified that could benefit of the usage of a embedded projectors in mobile phones and others which will not. These applications include those that require and visualize a great amount of detailed information, these including maps, web browsing, document viewing, picture browsing and video playing. On the other hand, projection is not always necessary, for example when making phone calls or when the user wishes to view private information. Finally, several participants mentioned that the projector would potentially provide several distinct advantages in a group based scenario, specifically including scenarios that involve group based tour planning or showing pictures viewing with friends.

**Privacy**

People are afraid of the fact that somebody who is passing might become aware of private information displayed by the projector and as a result they feel less reluctant and comfortable using it. With regards to the issue of privacy, we can distinguish three levels of privacy control that can be considered: private (at home), typically involving family where the user feels comfortable in projecting information; semi-private (office, meeting); and a public environment, like a train station, airport or shopping outlet. One can assume that many people will not have a problem with projecting a map onto a wall if for example they highly depend on this particular interaction in finding their way to the airport. However, showing pictures taken at a party is probably not acceptable in such a context, as this strongly depends on the user, the application, and the context. It can be assumed that the corresponding behavior should be controlled explicitly by the user or implicitly by the mobile phone. Such settings would be comparable to profiles like 'silent', 'meeting' or 'noisy environment' we currently find in mobile phones today.

# 9. CONCLUSION

The predicted integration of pico projectors in mobile phones has the clear potential to lead to an improvement of existing applications in which the user has to interact with a great amount of information and will also lead to new interaction techniques. This paper analyses how map based applications can benefit from the higher resolution and size when using a projection when compared to a conventional mobile phone screen.

The presented research provides clear evidence of several distinct advantages, such as improved task completion time, reduced number of errors and higher user satisfaction. The main reason for this is the fact that a bigger part of the map can be shown on the projection due to the higher resolution thus resulting in more available information. Map labels and icons can be read faster when projected as they have a larger relative size and thus appear clearer, removing any ambiguity when compared to view maps using the mobile phone display. However, when it comes to interacting with the keypad of the mobile phone, its screen plays an important role for the provision of corresponding feedback.

We hope to perform more longitudinal studies in the future in order to overcome the novelty effect of using a phone with a projector. This will certainly lead to new insights from users and will uncover possibly existing usage issues. Furthermore, we plan to carry out a range of evaluations based on more realistic prototype applications in a practical context. In addition to this, we hope that other groups will analyze the implications of using projector phones in order to further explore the issues surrounding this novel hardware.

Within our future work, we plan to evaluate typical usage scenarios, benefits and possible applications of using projector phones in a collaborative and group setting.

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# 10. REFERENCES

[1] Forman, G. H. and Zahorjan, J. 1994. The Challenges of Mobile Computing. IEEE Computer. 27 (4).

[2] Baudisch, P. and Rosenholtz, R. 2003. Halo: A Technique for Visualizing Off-Screen Locations. In Proceedings of CHI 2003 (Fort Lauderdale, FL, April, 2003), 481-488.

[3] Patel, D., Marsden, G., Jones, S., and Jones, M. 2004. An Evaluation of Techniques for Browsing Photograph Collections on Small Displays. In Proceedings of Mobile HCI 2004.

[4] Madden, D. CES 2008: DLP shows off working Pico projector prototype. 7.1.2008. http://www.pocket-lint.co.uk/news/news.phtml/12082/13106/pico-projector-prototype-shown-off.phtml

[5] NTT DoCoMo I-area, http://www.nttdocomo.co.jp/english/service/imode/site/i_area.html

[6] TomTom. PDA/Mobile navigation. http://www.tomtom.com/products/category.php?ID=2&Lid=1

[7] Chittaro, L. 2006. Visualizing Information on Mobile Devices. Computer (Mar., 2006), vol. 39, no. 3, 40-45.

[8] Cheverst, K., Dix, A., Fitton, D., Kray, C., Rouncefield, M., Sas, C., Saslis-Lagoudakis, G., and Sheridan, J. G. Exploring bluetooth based mobile phone interaction with the hermes photo display. MobileHCI 2005 (Salzburg, Austria, 2005).

[9] Greenberg, S., Boyle, M., Laberge, J. 1999. PDAs and shared public displays: Making personal information public, and public information personal. In Personal and Ubiquitous Computing, 3 (1-2), 54-64.

[10] Raskar, R., van Baar, J., Beardsley, P., Willwacher, T., Rao, S., and Forlines, C. 2005. iLamps: geometrically aware and self-configuring projectors. In ACM SIGGRAPH 2005 Courses J. Fujii, Ed. SIGGRAPH '05.

[11] Beardsley, P., Van Baar, J., Raskar, R., Forlines, C. 2005. Interaction Using a Handheld Projector. IEEE Computer Graphics and Applications (Jan/Feb, 2005), vol. 25, no. 1, 39-43.

[12] Cao, X., Forlines, C., and Balakrishnan, R. 2007. Multi-user interaction using handheld projectors. In Proceedings of the 20th Annual ACM Symposium on User interface Software and Technology (Newport, Rhode Island, USA, October 07 - 10, 2007). UIST '07. ACM, New York, NY, 43-52. DOI= http://doi.acm.org/10.1145/1294211.1294220

[13] DLP Technology. http://www.dlp.com

[14] Miles, S. CES 2008: 3M create mini projector for mobile phones. Accessed on: 4.1.2008. http://www.pocket-lint.co.uk/news/news.phtml/11967/12991/3M-mini-projector-mobile-phones.phtml

[15] Microvision, http://www.microvision.com/pico_projector_displays/index.html

[16] Meyer, D. Mobile-friendly projector debuts at CES. 7.1.2008. http://news.zdnet.co.uk/communications/0,1000000085,39291949,00.htm

[17] Dredge, S. Nokia World: Fancy a 100GB mobile phone with a built-in projector? November 30, 2006. http://www.techdigest.tv/2006/11/nokia_world_fan.html

[18] Lewis, J. R. 1995. IBM computer usability satisfaction questionnaires: psychometric evaluation and instructions for use. Int. J. Hum.-Comput. Interact. 7, 1 (Jan. 1995), 57-78.

[19] Hart, S. G., Staveland, L. E. 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In Human Mental Workload (Amsterdam, North Holland, 1988) Press. 239-250.

[20] Rohs, M., Schönig, J., Raubal, M., Essl, G., and Krüger, A. 2007. Map Navigation with Mobile Devices: Virtual versus Physical Movement with and without visual context. ICMI'07(Nagoya, Aichi, Japan, November 12-15,2007).

[21] Reilly, D., Rodgers, M., Argue, R., Nunes, M., and Inkpen, K. 2005. Marked-up Maps: Combining Paper Maps and Electronic Information Resources. In Journal of Personal and Ubiquitous Computing.