Mobile Multi-Display Environments

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ABSTRACT
Mobile devices are increasingly being fitted with more than one display, presenting a new breed of Mobile Multi-Display Environments (MMDEs). It is however still unclear how the extra display fits within the mobile devices' ecology in terms of visualisation and interaction. My research explores the alignment between multiple displays in a mobile environment and how different alignments affect usability and the choice of a suitable interaction technique. In order to investigate those properties and adapt them to various use cases, I will build a steerable projection system to study different alignments, then analyse visual separation effects in MMDEs and finally explore the possibilities offered when the displays are overlapping.

Author Keywords
Pico-projector, mobile multi-display environments.

ACM Classification Keywords
H5.2. Information interfaces and presentation: User Interfaces.

General Terms
Design, Human Factors.

INTRODUCTION
The market for pico-projectors is fast growing, expected for 27 million units to be produced by 2015 [5]. They are either sold as an independent mobile display or embedded within existing mobile devices such as phones, cameras and game consoles. The pico-projector is typically fitted in a fixed position on the device with little regard to how it fits within the general device ecology both in terms of existing displays and suitable interaction paradigms. My dissertation will explore the link between the alignment of multiple displays in a mobile MDE, the usage scenario and the choice of a suitable interaction technique.

The main aim of my study is to investigate how different screen-projection alignments affect usability. For this purpose, I have divided my research around three research projects (Figure 1).

Steerable Projection
The first project consists of understanding which alignments between the phone and the projector would be best suited for different types of applications. For this purpose, I have developed a mobile steerable-projection system that yields a reconfigurable screen-projector alignment that can be used on-the-go. The study run to validate the use of a steerable pico-projector phone showed that different alignments between the phone's screen and the projector are best suited for different tasks. For a task that consisted in following directional arrows, no participant chose the projector-screen alignment that is currently preferred by handset manufacturers. I have then proposed different alignments to suit various situations.

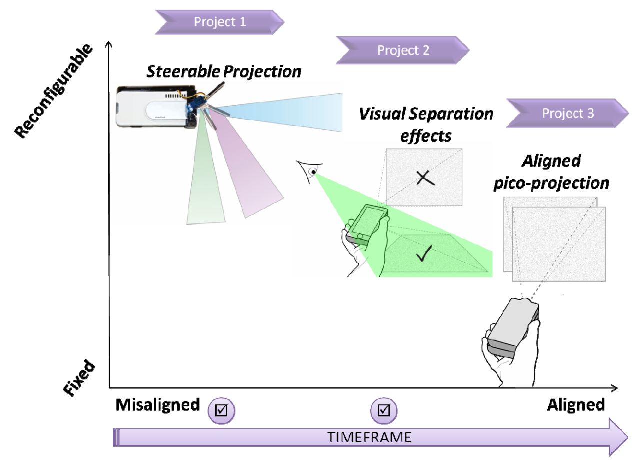

Figure 1: Research Overview.

Visual Separation effects
For the second project, I wanted to identify how users were physiologically affected by the different screen-projection alignment. I wanted to determine if concepts of display placements in the MDEs literature [7,8] could be re-used in the mobile environment. I ran a study evaluating the visual separation effects of aligned and misaligned screen-projection systems in the mobile context. The main observation from the study was that there were 30% more eye context switches when both displays were in the same field of view. From this study, I have drawn conclusions on display positioning and the suitability of interaction techniques.

Aligned pico-projection

My next project will be exploring design and interaction paradigms when two projected displays are in the same field of view on a single mobile device. Multiple projected displays can be used to increase display real estate, resolution of projection or even offer 3D projection. This project and subsequent study on dual-pico-projection will expand the current state-of-the-art of multi-display environments.

Methodology

In order to explore different display alignments, I will build three prototypes of mobile devices with embedded pico-projectors. I will then conduct user studies to evaluate those prototypes and adapted user interaction techniques. I will use quantitative as well as qualitative measures from those user studies to evaluate the different alignments and how the pico-projector fits within the ecology of mobile devices. From those results, I will put forward design guidelines that will help researchers and designers when building new systems. These three research projects will allow researchers and designers to have a better understanding of how pico-projectors should be integrated with existing mobile technologies.

STEERABLE PROJECTION

When embedded, the pico-projection unit is typically fitted at the top of the mobile device without any regards to other displays on the device or without integrating any specific interaction technique. While, mobile projected displays are being presented as a new category of devices for co-located collaboration [1], it is important to understand how they fit within mobile devices with regards to other displays and interaction capabilities.

Screen-projection alignments

To understand how the projected display fits within mobile phones' ecology and which screen-projection alignments are best suited for different types of applications, I have prototyped a mobile steerable projector phone [3, 4]. This prototype allows for different alignments between the phone's screen and the projection. In a first step, three applications have been developed, a visual search task, a reading task and a navigation task.

The prototype is a fully mobile device consisting of a phone, a pico-projector and a Bluetooth electronic board that receives position information from the phone and moves a mirror placed at the top of the projection lens accordingly (Figure 2). For each of the three applications, the user can choose between three positions of the projection labelled: Wall, Desk and Floor, respectively corresponding to no inclination, a 30° and 50° downward inclination.

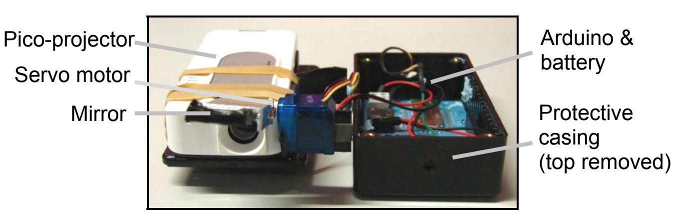

Figure 2: Prototype opened with top case removed.

I ran a study with 18 participants (6 individuals and 6 in pairs) who could chose any angle they preferred on-the-go for each task. The first task consisted in finding differences between two images on the projection; the second one consisted in reading an email out loud from the projected screen while the third task required from the participants to follow projected arrows through a maze.

The results showed that users had different preferences for different applications. An important outcome is that the fixed projector-screen 90° angle, currently preferred by manufacturers, is not suitable for all tasks. When mobility was involved, such as when the user is walking, so there is no wall projection space available at all time; this angle was never chosen by the participants, who preferred projecting onto the floor. Floor projection provides a continuous projection space even when the user is walking. Participants were particularly excited by projecting onto the floor and by the possibility to use an application without having to look at the phone's screen.

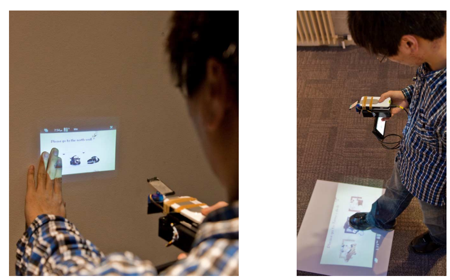

Figure 3: Interaction by touch on the projection, using hand (left) of foot (right).

Interaction technique

My next step was to implement some interaction techniques that would correspond to different projector and phone alignments. The idea was that if the interaction would be done using image processing techniques, instead of current touch on the phone's screen, the alignment between the camera on the device and the projection would also influence the choice of interaction technique.

A set of interaction techniques was then designed for different pico-projector and phone's camera alignments. The first technique consists in using touch and dwell time to select items on the projection with either hand or foot (Figure 3); this is the case where the projection and camera are aligned. The second technique consists in waving at the camera with hand or foot from left to right or right to left to browse forward or backward through pictures or slides.

We ran an informal user study and found out that "touching" the projection is actually not a suitable interaction paradigm for wall projection while "stepping" on the floor projection is both efficient and intuitive. In the misaligned case, browsing by waving with hand or foot was simple and intuitive, and could in the future be used for browsing through menus for example. A main challenge for future designs will be to create adaptive interaction techniques for reconfigurable mobile projected displays.

VISUAL SEPARATION EFFECTS

> *Visual separation is the division of information across space in Multi-Display Environments (MDEs)*

Some MDE literature explores how different displays need to be arranged compare to one another and to the user in order to limit the effects of visual separation [7, 8]. The main factors affecting visual separation in MDEs are the size, depth, bezels and whether the displays are in the same field of view. While there is an increasing number of mobile devices that can be qualified as Mobile MDEs, many of them fitted with heterogeneous displays, it is still unclear how the literature and guidelines for the placements of displays in MDEs can be translated to the mobile context.

In order to evaluate visual separation effects in MMDEs and find out whether current literature on MDEs can be applied, we ran a study to find out what the visual separation effects are for MMDEs, in particular with heterogeneous displays (a screen and a projector) of different sizes and displaying at different depths [2]. Since two of the main factors affecting visual separation were fixed in our experiment, we used another main factor, the field of view (FoV) as independent variable. We proposed three positions (Figure 4), one where both displays are in the same FoV (Floor), one where displays are in different FoV but same plane (Front Wall) and one where the displays are in different planes and FoVs (Side Wall). We also tested a fixed condition where the mobile is mounted on a tripod and a mobile condition where the user is free to move with the device.

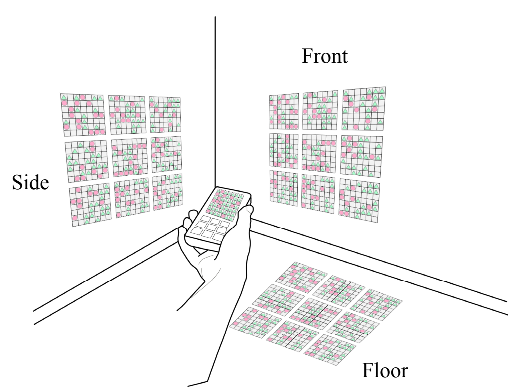

Figure 4: Experimental design: The phone is held while the pico-projector project onto one of those three positions (Floor, Front and Side Wall).

The task consisted of a visual search task where 12 participants had to recognise which matrix out of 9 on the projected display corresponded to the one shown on the mobile phone's screen. Each participant was given 8 tasks for each one of the 6 alignment conditions. We gathered quantitative data such as completion time and error rate and also qualitative data by observing the participants during the task and through the use of a post-study questionnaire. We also gathered eye-tracking data using a non-invasive Tobii® Mobile Eye tracker.

While post-study questionnaire revealed that participants perceived the Floor position as being faster, we did not find any significant difference in the overall completion time and error rate. In contrast, we found that there were 30% more context switches (a context switch occurs when the participant look from a display to the other) in the Floor condition. The post-study questionnaire also revealed that the favourite position across all conditions is Mobile Floor and that 9 out of 12 participants preferred a mobile position.

The most interesting result is that for the same completion time there are 30% more context switches when both displays are in the same FoV. Eye switches appear cheaper to perform when displays are in the same FoV. Another interesting result is that across all positions, half of the participants preferred projecting on the floor. Finally, we did not find any significant difference in the completion time, which shows that the current guidelines for traditional MDEs do not seem to apply to MMDEs and that new guideline need to be issued.

We present a set of design recommendations: multiple displays on a mobile device should ideally be placed in the same FoV; floor projection should be considered when designing new systems; scenario of interaction while on the move should be considered since mobility does not increase visual separation effects; there is more flexibility in positioning multiple displays on MMDEs than in traditional MDEs. The main challenge for future research will be to draw design guidelines for mobile MDEs that are often highly heterogeneous MDEs.

ALIGNED PICO-PROJECTION

Drawing from the results obtained in the visual separation study, it is clear that there are many opportunities offered by multiple displays in a same FoV in MMDEs. There is previous research on the alignment of multiple displays on a mobile device such as Codex [6] and on overlapping multiple projectors in a mobile environment [1]. Yet, the research space for overlapping displays in mobile computing is underexplored and my work will investigate how display estate can be increased; how additional content can be added on a projection and even how 3D can be introduced to mobile projection systems. That said this also presents some new technical challenges at finding appropriate enabling technologies.

The notion of introducing 3D to mobile projection is especially interesting as it would allow either 3D on a single device available at all times or enable 3D by bringing two projectors from two individual personal devices together, giving a new dimension to collaboration. Moreover, we could even envisage having different views for different users depending on their position with the projection and embedded depth camera could be used for interacting with the device.

Next Step: Technology for overlapping pico-projection

Currently, 3D technology is well developed for traditional projection but not yet available for mobile environments. Bringing 3D to mobile environments would allow portable augmented reality applications, such as gaming, as well as bringing multiple layers of information onto the real world. I will apply techniques for 3D projection such as using polarized film and shutter glasses to multiple pico-projectors in order to realise a prototype for portable 3D projection. I will consider what alignments (i.e. positions) between the projection and the user affect visualization.

Next Step: Interaction technique for different overlapping configurations

Once the prototype is developed, I will implement a suitable interaction technique for users to manipulate items on the projected display. In recent years, there has been an increasing amount of 3D interaction done using a depth camera [9]. It will therefore be my first choice for implementing interactions with projected 3D content.

On completion of the prototype and interaction technique, I will evaluate how the user needs to be located with respect to the device in order to be able to both see the display properly and interact with its content. I will then test this in the case of two users, which will show how two co-located users need to be placed in order to create a new 3D display together. I will then investigate how this positioning can affect users in terms of proxemics.

CONCLUSION

My research will explore how the different alignments of displays in mobile MDEs affect the usability of the device. I will investigate different alignments of a pico-projector on a phone using a reconfigurable steerable mobile projector phone, I will then study visual separation effects for different screen/projection alignments and I will finally research the possibilities offered by overlapping projected displays on a mobile device. My research will contribute to and provide a better understanding of mobile multi-display environments and how the different displays can be fitted within the device without disturbing the global ecology. It will also deliver design considerations for adapted interaction techniques on mobile MDEs.

RELEVANCE TO UIST DOCTORAL SYMPOSIUM

Participating in the UIST DS will allow me to benefit from experienced researchers as well as other graduate students' input on my work. This will give me the opportunity to present my work and spot potential weaknesses in the projects I have already completed, as well as help to shape my experimental setting for my final project in order to produce a comprehensive piece of work as a PhD dissertation.

I believe I can contribute to the UIST DS by taking part in intellectual discussions with other participants about their work and exchange ideas on future research. My main research interests are HCI for mobiles technologies, development of new enabling technologies, VR and AR as well as new interaction paradigms.

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