Ubiquitous Displays in dynamic environments: Issues and Opportunities

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Abstract

This paper discusses possible technologies and the issues involved in creating ubiquitous display landscapes for the dynamic environment of the future office. Ubiquitous display solutions are required to support flexible working methodologies, where office space is frequently reconfigured as project teams are formed then disbanded. Display landscape solutions are available by embedding displays in mobile furniture, by projecting displays onto surfaces in the environment, by using portable handheld devices, or by using a combination of all techniques. However, many research questions still remain before viable ubiquitous display solutions can be implemented. This paper identifies these issues and outlines directions for future work.

1 Introduction

In the modern world one display is rarely enough do deliver all the information content we request or have pushed at us. Daily activities such as writing letters and email, browsing the web, shopping on-line, socialising with friends, or even watching TV generally benefit from more screen real-estate. To accommodate the need for more display space, an increasing number of people use multiple computer monitors in their workplace. Yet as a result, we are currently in danger of filling all available desk space in the office with large numbers of display devices. These displays are expensive and tie users to a physical location, focusing all interaction on small "windows" into the virtual world of our office machine. Small mobile displays embedded in phones and PDAs do not alleviate this situation. They are tolerated due their usefulness and handy portable size, but "in your office, where you spend a great deal of time and work on 'big' projects, small displays can be frustrating" [1].

The need for more display space has led to a quest for alternative display solutions. New technologies are now being researched that developers claim will change the way we view current displays. Future displays proposed such as the projector based systems envisioned by Welch et al. [1] tend to involve a paradigm shift away from computers having their own fixed display and towards making use of the multiple surfaces that already exist in the environment. Welch et al. see every-day surfaces such as desks, tables, cupboards, walls and even floors all becoming the displays of the future. These potential display surfaces should be accessible where ever and whenever we need them, unobtrusively available, thus enabling new and creative ways of interacting with information. The fact that these displays will be ubiquitous makes them powerful, even if they only convey small amounts of information.

Obviously we cannot embed displays into each surface of every object manufactured in the future – this is not a sensible or obtainable goal. We therefore need to examine other solutions to creating viable ubiquitous display solutions. In this paper we discuss new developments in ubiquitous displays. We survey ubiquitous display technologies and identify issues in developing ubiquitous display systems for dynamic environments.

2 Dynamic Displays for Dynamic Environments

The office of the future will be a dynamic environment incorporating reconfigurable work areas dynamically created to fit the task currently being worked on [2]. Spaces have to be configured for one project and reconfigured for the next as teams come together and disband [3]. Moveable walls and mobile multipurpose furniture will allow these rapid short-term changes, as well as a longer term evolution of the whole office environment as the space is adapted over time to suit the occupant's working styles.

Offices of today have barriers to this vision in the form of most office furniture not being designed with wheels, so lacking any sort of mobility. Large amounts of computer equipment would also have to be moved with each desk, and there would currently be a requirement for services such as power and data to be provided in the correct locations for every possible configuration of furniture (leading to large amounts of redundancy). Only with a combined ubiquitous display and flexible furniture solution is the goal of flexible, dynamic office environments attainable.

While furniture manufacturers are now beginning to provide mobile furniture solutions, display solutions lag behind. Nevertheless, visions for future office displays are emerging in the form of display technologies which make use of the multiple surfaces that already exist in the environment. In addition, a series of enabling technologies have emerged which will have a significant impact on the design of future display solutions such as miniaturised projectors, high-intensity LEDs, low power short-range wireless networks [4], and long duration mobile power solutions supplied by alternative technologies such as miniature fuel cells [5]. However, we are in the very early stages of ubiquitous display system development and many open questions remain. In the following section we will provide an overview of current and future ubiquitous display technologies.

3 Ubiquitous Display Technologies

Many different approaches to ubiquitous displays are being investigated, ranging from display walls and steerable projectors to new display materials. Figure 1 provides an overview of the main characteristics of the various technologies identified as being suitable for ubiquitous displays. In the following we will discuss these technologies in more depth.

3.1 Display Walls

Wall sized displays such as the Princeton University's Scaleable wall [6], the NCSA Display Wall [7] or MIT DataWall [8] appear to offer large scale high resolution display solutions to the small display area problem. However, these systems are not suitable for the office of the future as the tiled rear-projection systems they employ take up a large floor space, need time consuming calibration and are fixed, not portable. More recently, much work has been done on creating ad-hoc front-projected multi-projector displays such as that by Raskar et al. in [9], but this still requires a large amount of space to set up and suffers from occlusion problems if users want to work close to the display.

Most display walls also require either expensive, high performance graphics workstations, or large clusters of low cost PCs rendering to the tiled projectors to be able to create a seamless high resolution display at video frame rates.

Display	Display Technology	Mobility	Occlusion Problems	Simultaneous Users	Space Requirement	Interactivity	Power Requirements
Traditional Computer Monitors	CRT and LCD	Fixed	No	Single	Small, desktop	With separate hardware	Medium, mains
Rear-Projected Display Walls [6,7,8]	Projection	Fixed	No	Multiple	Large area, behind display	With separate hardware	High, mains
Front Projected Display Walls [9,10,11,14,15]	Projection	Mobile, ad-hoc creation	Yes	Multiple	Large area, in front of display	With separate hardware	High, mains
Steerable Projector-Camera Systems [12,13,14,15,16,17]	Projection	Fixed but steerable image	Yes	Multiple ?	Small area for projector, requires clear view of multiple display surfaces	With system camera, direct interaction with image	Medium, mains
Mobile Projectors [9,19,20]	Projection	Portable	No	Single	Small handheld, needs light coloured surface for projection	Potentially with gestures, movement, or direct interaction with image	Low, battery
E-Paper [21,22]	E-paper	Portable	No	Single	Small handheld, flexible displays rollable for storage	Potentially write-on surfaces	Low, battery

Figure 1. A Comparison of Display Technologies for Ubiquitous Display Solutions

3.2 Virtual Rear Projection (VRP)

While careful mounting of projectors can reduce the problem of occlusion in front projected displays, this only holds for static environments. In dynamic environments, different furniture configurations could easily create a case where there are large portions of possible display area obscured from fixed projectors by bookshelves or other large furniture. There is also the problem of the office inhabitants, who will not just sit passively at their desks, but will move through the display environment, creating dynamic occlusions of projected displays.

Solutions to this problem have been demonstrated in [10] and [11] by using multiple projectors, projecting from different positions, with overlaid projections to create a "Virtual Rear Projection" (VRP). This approach works well when front projection is required (although users still preferred rear projection systems in [11]), but requires multiple projectors, at least doubling the equipment costs for each display.

3.3 Steerable Projector Camera Systems

Another solution to front projection occlusion is to use a system that is able to project onto a multitude of surfaces from one fixed projector, such as the steerable projector-camera system initially developed by Pinhanez at IBM. By allowing the system have some choice in which surface it projects its display, it can dynamically change surfaces if its projection becomes occluded and also creates the potential for novel display types such as user following displays [12].

The system Pinhanez named the Everywhere Display (ED) [13] uses a projector with a computer controlled pan and tilt mirror to enable projection of the computer display onto any planar surface within the system's projection envelope. A co-located pan and tilt camera allows interaction with the display using finger gestures and pointing. In essence "it creates a harmless 'robotic arm' of light that can affect people in multiple ways" [13].

Much extension work has been performed on the projector-camera system concept by researchers, potentially allowing today's EDs to be viewed by mobile viewers with the image projected on arbitrary shaped surfaces [14] and correcting for any surface texture and colour [15].

The ED can allow users to reclaim the desk space currently used by displays and computers, instead using multi-surface interactive interfaces projected from the ceiling. Steered projectors also have the benefit of flexibility, for example, if multiple EDs were installed in an office and one user went home, then the projector they were using would be immediately available as an additional display for other users.

The ED projector presented by IBM relies on a known 3D geometric model of the environment to decide both on which surface to project its imagery (especially relevant for user following displays) and how to warp the computer image to achieve a visually correct projected display. Other projector-camera system researchers rely on visual acquisition of the display surface geometry by a plethora of methods – structured light, imperceptible structured light, shuttered light and stereo vision.

These surface calibration methods generally assume a static environment where the display and projector relationships are fixed. However, Raskar et al. demonstrate mobile projectors (discussed below) in [9], Borkowski et al. demonstrate a dynamically tracked portable projected display screen in [16] and Yang and Welch present a continuous calibration method that could potentially be used in dynamic environments in [17]. Tokuda et al. also propose a different method in [18] by using a Laser range finder in combination with the camera to rapidly scan the environment, generating a coarse resolution room model and tracking any dynamic changes.

These calibration techniques could allow EDs to be placed into a dynamic environment such as the office of the future and form part of a ubiquitous display environment. If multiple projectors were installed they could easily collaborate on an ad-hoc basis to create high-resolution displays spread over single or multiple, static or dynamic surfaces.

3.4 Mobile projectors

It was Raskar at the Mitsubishi Electric Research Labs (MERL) who popularised the idea of handheld projector–camera systems, developing a mobile projector-camera system that fit into a large toolbox [9]. Despite this achievement the system still relied on a connected mains cable for powering the video projector. However, the promise of Laser and LED projectors that can run for hours on batteries heralds a new era in mobile display technology.

Cambridge University spin-off company Light Blue Optics has already announced monochromatic hologram-based 2D display projectors that have the potential to be miniaturised to pocket size [19] and claim they will have a pocket colour display projector available in two to five years.

Lumiled has also developed a full colour red, green and blue (RGB) LED illuminator for DLP pocket projectors giving 40 lumens total lamp output, and 15 lumens out of the projector. When projected onto a white screen surface, Lumiled claims the display brightness compares well to LCD laptop screens if sized up to 15 inches diagonal [20], so has great potential for handheld applications and miniature fixed display projectors in close proximity to display surfaces.

As LED technology improves, this brightness can only increase. However, the big problem still to be solved is the heat generated by the LED chips. The LED chip junction temperatures must be kept at 25ºC for maximum brightness, which currently requires large heatsinks or forced air cooling for high power versions.

3.5 E-Wallpaper

E-Paper has been demonstrated at research labs around the world in both black and white and colour versions, but so far only Sony has brought a product to the market in terms of a rigid 6” diagonal portable display, called "LIBRIé" [21]. The technology will in future potentially allow a completely digital replacement for paper due to its thin, flexible and high contrast paper-like display characteristics.

More recently, the Korea Electronics Technology Institute (KETI) announced that its researchers had developed a method to create e-paper by coating ordinary paper [22], potentially paving the way for very low cost large-scale displays. When such displays are finally brought to market, in addition to portable "paper-replacement" applications, it should be possible to embed them as a front surface to common objects – cupboards, desks, doors and even install them on walls like wallpaper. In combination with touch screen overlays, such as those produced by London based U-Touch [23], or load sensors systems such as the Lancaster University Weight Table [24] the surfaces themselves could advance beyond mere display surfaces and become interactive interfaces.

While covering our environment in e-paper at first sounds like an attractive idea, there are still many technological hurdles to be overcome. There is a question of how durable and resilient e-paper surfaces are. For example, if a drink was spilled on an e-paper covered desk, we would not want the whole desk display to fail.

At the demonstrated 170 pixels per inch (ppi) resolution e-paper will exceed current high-end PC monitor display resolutions (1600x1200 pixels) as soon as it is manufactured at 12" diagonal, so new graphics hardware will be required to operate large displays directly from a PC at video rates. If we wanted to go one step further than PC monitors and use embedded e-paper surfaces as independent "smart" surfaces then its high resolution again causes problems due to the amount of data that needs to be transmitted over network links for video rate data presentation unless we resort to lossy compression algorithms such as the use of MPEG in [25].

4 Towards Ubiquitous Display Landscapes

In Section 3 we presented a range of display technologies that could contribute toward a ubiquitous display environment in the office of the future. However, not one display technology is so cheap, flexible and easily available that it can currently be used in isolation to form a ubiquitous display landscape. Instead, the future office will probably require a combination of technologies to become a viable display system.

The displays in current offices are also usually connected to one machine, and each system is considered a separate entity, with their own set of applications and capabilities. There is limited interaction between systems, so information does not generally migrate between displays without explicit user interaction. For example, if a user is sat at a desktop computer wanting to look at the photos taken on a mobile phone, then they would have to explicitly tell the phone to download them to the desktop machine over a Bluetooth network link.

There is therefore clearly a need for ubiquitous display solutions to be more than merely a collection of displays. Rekimoto at Sony CSL labs demonstrated work in this area at CHI 1999 [26], showing a spatially continuous virtual surface encompassing laptops, a projected desk and a display wall. This work illustrates very well the aim for ubiquitous display systems to be a cohesive and collaborative display network.

Rekimoto also demonstrated information transfer between computers using techniques known as "hyperdragging" or "pick and drop" following recognition and tracking of the devices' fiducal markers by the desktop display's camera. By moving the cursor to the edge of the laptop display, it appeared on the projected desktop display and could be "Hyperdragged" to any of the other machines, allowing drag and drop of information at will on any display by any user. Other interaction techniques (such as cursor throwing) for large displays have also been demonstrated by Geiβler in [27] and Hascoët in [28].

5. Open Research Issues

Many issues still remain before a truly useful and comprehensive ubiquitous display system can be deployed. The individual display technologies discussed in Section 3 create specific issues of their own. Additionally, the issues identified below are universal to all ubiquitous display systems and need to be addressed in future research.

- **Seamless Multi-user interfaces**
  The "windows on the world" metaphor used by the Microsoft Windows™ interface and similar desktop window managers perhaps also now requires a re-think as information is no longer concentrated on a single monitor but can be spread across ambient, peripheral and focal displays in the ubiquitous display landscape. The fact that these display landscapes can form large displays also allows collaborative working scenarios where multiple people interact with the same surface or the same application but on multiple surfaces simultaneously, which will require explicit user interface development to support this interaction methodology.
- **Context awareness**
  For a ubiquitous display system to be able to perform well it needs to know where the user is and what the user is doing. The use of 3D environment models for user location is not possible as the environment is dynamic, so location and context sensing is required through the use of sensors – either in the environment, or in the displays themselves. If steerable projector-camera systems are employed then computer vision techniques could be used with the system camera. For other systems the office surfaces and artefacts could be combined with ubiquitous sensor networks such as demonstrated by the Smart-Its project [29]. However, more research is required to determine exact mechanisms for user data collection and dissemination in ubiquitous display landscapes.
- **Effective development support**
  Application New methods of developing applications will be required if the user interface can potentially span multiple disparate surfaces. For example, ways of allowing the applications to determine what displays are available, the display locations and capabilities are required. Without knowing this information applications would be limited to a single display.
- **Privacy**
  By moving away from relatively small computer monitors there is the potential for sensitive information to be displayed over a larger area and viewed from many more angles. If the user has no control over where information is displayed, then the wrong display could be used by the system at the wrong time. For example, we generally do not want our bank details to be displayed in foot high letters by a projected display on the wall for all to see. Consequently, work is required on context awareness both of the information the display system it is showing and of what the

user is trying to accomplish. There should also be a way for the user to explicitly select displays where certain applications or information will always be displayed.

- **Ownership**
  The office of the future is a dynamic environment, with frequent moves of furniture and inhabitants. If displays are truly ubiquitous then there should be few problems with ownership – there will be enough displays for everyone to work wherever and however they want. However, issues could develop if, for example, a ubiquitous display system consisted solely of ED systems deployed as one per user. If one users' work requires a high resolution or large display area, then multiple EDs would be required. If all ED systems were in use then how could this conflict be resolved? Should all displays be considered a shared resource? Should a request based or time and usage limit system be introduced? Further work is required to resolve these questions and determine possible implications of ubiquitous display systems on working methods.

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