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Experiences and Challenges in Deploying Potentially Invasive Sensor Systems for Dynamic Media Applications

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***Abstract*- This paper describes a series of projects that explore a set of dynamic media applications built upon a potentially invasive sensor system – the Ubiquitous Media Portal, featuring high-resolution video and audio capture with user ID/tracking capabilities that we installed throughout our facility. In addition to sensors, the portals provide a display and loudspeaker to locally display information or manifest phenomena from virtual worlds. During an eight-month long period, we implemented four different applications to explore acceptance by our building-wide users. Our results provide insight into how different levels of information presentation and perceived user control can influence the user acceptance and engagement with such sensor platforms in ubiquitous deployments.**

I. INTRODUCTION

Ubiquitous media sensor/display systems have great potential for integrating VR applications into daily life and activity. They allow a fluid and dynamic combination of real and virtual, with densely deployed sensor networks continually shuffling and metaphorically manifesting fine-grained information between domains [1]. Our research group first proposed the concept of "dual reality" (later evolving into the more generic term "cross reality") as an environment resulting from the interplay between the real world and the virtual world, as mediated by densely-deployed networks of sensors and actuators [2-3]. The idea was initially explored though the implementation of a power strip imbued with sensing, actuation, computation, and communication capabilities in order to intrinsically form the backbone of a sensor network in domestic and occupational environments [4] and realized in a set of demonstrations that linked a floor of our lab to an analogous virtual lab space in the Second Life online virtual world [3, 5].

Privacy issues, however, tend to limit ubiquitous image/video/audio sensor deployments of the kind needed for immersive cross-reality applications. In this paper, we describe the experiences and challenges in deploying such a potentially invasive sensor system that we have developed – the Ubiquitous Media Portal (UMP)[1]. In order to manifest virtual and remote phenomena into the user's physical space for two-way interaction, the UMPs are equipped with a display and loudspeaker as well as several invasive sensors such as a motorized pan, tilt, and auto-focus video camera and a stereo microphone. For the purpose of deploying a ubiquitous sensor network as part of our building infrastructure, we constructed 45 UMP nodes and installed them throughout our building. Every application that ran for any significant length of time on the UMPs was opt-in, where users can opt-in with wearable sensors or through selections from touch screen inputs. This paper describes the experiences and challenges in constructing and deploying such an invasive sensor system and points out issues that we encountered in gaining users' trust and acceptance in support of our building-wide installation.

II. SENSOR NETWORK INFRASTRUCTURE

Our initial work in sensor systems for ubiquitous VR applications were based on our Ubiquitous Media Portal (Figure 1), a platform for capturing sensor and video data paired with an interactive display. The main "invasive" feature of the UMP is its motorized pan, tilt, and auto-focus video camera, capable of recording and streaming DVD-quality video and snapping 3.1 megapixel still images. The device accommodates slotted flash memory, allowing a large local video store in addition to enabling fast streaming over the wired network. The UMPs also provide a small touch-screen display and audio speaker for a two-way communication. A variety of environmental sensors are included - PIR motion sensor, light sensor, stereo microphones, vibration sensor, and temperature/humidity sensor (SHT15). The UMPs also feature active IR links that can communicate with active badges to identify individuals who are facing the portal.

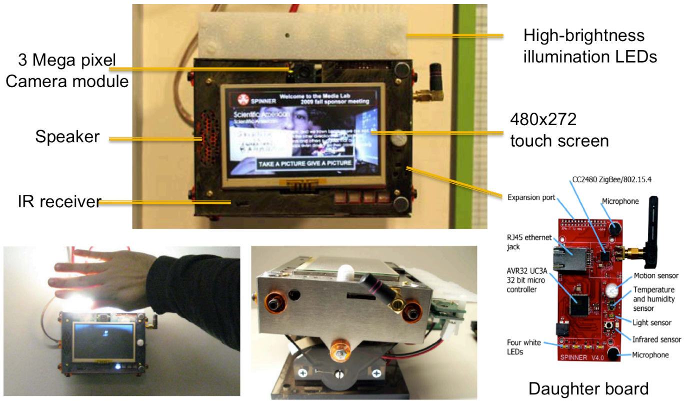


Fig. 1. Ubiquitous Media Portal – a platform for capturing sensor and video data paired with an interactive display.

At the beginning of our deployment, we encountered significant privacy concerns from several people in our building, especially from those unfamiliar with this project. People would retaliate in different ways – e.g., Fig. 2 (left) is a picture taken by one UMP node, which was purposefully blocked by a plant. Several approaches were implemented for solving the privacy issue during our development, including adding an on/off lamp switch inline to the power cord to enable users to directly deactivate UMPs (Figure 2 - right). Users can thus switch off the power anytime they wish for protecting their privacy. The switch obviously cuts the source of power and cannot be controlled over the network; hence another user or UMP researchers have to manually turn it back on. A less drastic approach that we pursued in a limited study kept the UMPs alive, but provided users with a configurable active badge system that allowed them to preset their personal privacy settings online and onsite [6-7], dynamically throttling the data sent out by proximate UMPs as they wandered through the building.

However, any approaches for protecting privacy are limited in improving user acceptance without a useful suite of applications running on the UMPs that engage building occupants and provide them a clear benefit in having these devices running.

In the course of our deployment thus far, we developed four different applications that we ran on the UMPs for extended periods. In this paper, we contrast the impact that these applications had on portal acceptance by deriving the on-vs-off time for each portal via tallying the periodic registration data packets sent from each activated UMP.

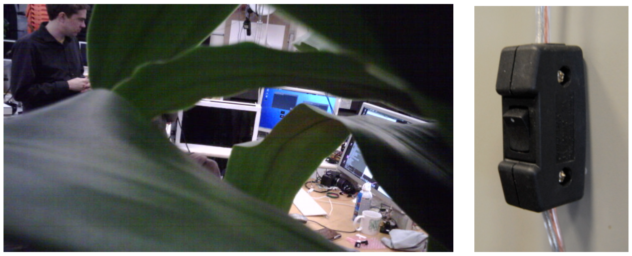


Fig. 2. Image from UMP camera, purposefully blocked by a plant (left) showing one of the many forms of resistance to privacy-invasive technology. Inline on/off lamp switch added in response (right)

III. APPLICATIONS

We have implemented four applications, which we term Awareness App, RSS Display, Cloud of Images and Mirrored Image Playback, each described in detail below. All ran on each of the 45 UMPs installed in the building during the course of eight months.

A. *Awareness App*

The awareness app was developed to show a continuous background video while offering users control over most features on UMPs, such as sensor data browsing, video streaming, and audio output. When no one was interacting directly with a UMP, the screen played canned video content, such as movies appropriate with the theme of an event hosted at our laboratory (Figure 4(a)). A user can then start interacting with the UMP through its touch screen. An onscreen button for muting audio output of the movie was provided, as well as an invitation for the user to touch the screen elsewhere to interact. Once a user initiated interaction, the application presented a map of the building on the portal's touch screen (figure 4(b)). The map was geo-labeled with information captured from UMP sensors at the respective locations, such as local motion/sound activity and whether someone else was interacting with another UMP. Using the sensor data as a guide, the user can zoom into the map and view more detail about a particular location sensed by a UMP. Once a particular remote location or a space (Figure 4(c)) is selected, the UMP will stream live video and audio from the remote UMP (or the virtual environment to which the UMP is connected). Some of our applications directed the remote UMP to display an "on-air" indication notifying the room that video was being streamed to another location in the building (figure 4(d)). Extensions to this application explored the ability for wearable devices to select and control the playback of the ambient movie. This allows video content to "follow" a badge-wearer around and playback from where it left off the last time the user approached a UMP.

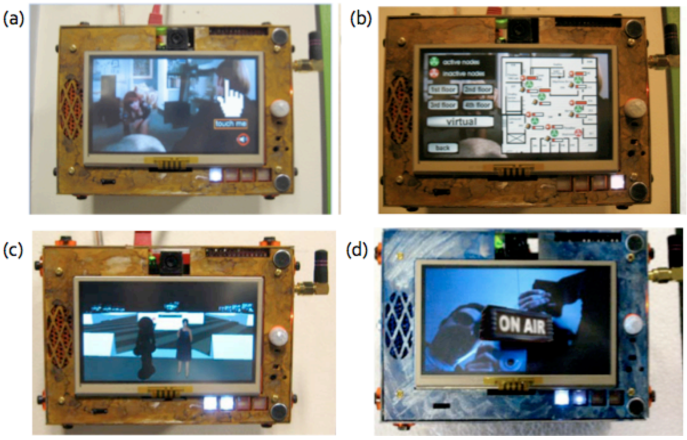


Fig. 4. (a)Awareness App in idle mode - the screen plays canned video content, such as movies appropriate with the theme of a hosted event (b) when activated, the application presented a map of the building on the portal's touch screen (c) Rendering of the UMPs corresponding virtual location in Second Life. (d) The remote UMP displays an "on-air" indication notifying nearby individuals that video is being streamed to another location in the building.

B. *RSS Display*

In order to compare and study user acceptance versus the utility provided by the system, we developed another application that provided no direction interaction for users but displayed dynamic information that could be relevant to them. As seen in figure 5, the touch screen displayed RSS (Really Simple Syndication) feeds from five different sources that were of the interest in our building, such as the latest news from our lab and institute. Different RSS feeds alternated every 30 seconds. This application has a neutral appearance, without any indication of the potentially invasive capabilities of this system.

Fig. 5. Picture of the RSS Display application.

C. *Cloud of Images*

An application named Cloud of Images was developed and first deployed during an event at the Media Lab with the theme of "*Interact - Inform - Inspire*." The Cloud of Images application enables any visitor to the space to take a still image using the UMP's camera and have it instantly displayed at all 45 UMPs in the building. This demo effectively converted the entire building into a digital picture frame, displaying up-to-the-minute captured images. In addition to the most recently captured image, RSS news information was overlaid. This invited people to move closer to the display, view the RSS feed and the image, and ultimately hit the button to capture their own image and add it to the cloud.

Fig. 6. (a) Cloud of Images application. (b)(c) After pressing the "TAKE A PICTURE GIVE A PICTURE" button, bright onboard LEDs light up for illumination.

Fig. 7. Example images captured by the Cloud of Images application.

Over the course of our first 3-day deployment, over 1500 images were captured and displayed. As people became more accustomed to the system, it saw some creative uses such as broadcasting announcements by capturing a written note.

A web interface was also developed for augmenting the functionality of this application. On the website, users can login with their internal username and password. Once logged in, the user can type messages or upload images to all UMPs. These functions allowed users to interact with the whole community through the portal platform.

D. *Mirrored Image Playback*

The last application we ran on the UMPs was called Mirrored Image Playback. Before the experiment, we had already run three different UMP applications. Also, detailed information listing the capabilities and functionalities of this system was emailed to the whole building community. People were hence aware of the UMPs and had already interacted with them for a long time. With Mirrored Image Playback (see Figure 8), the only display users see is the real time image loop back from the camera. This allowed us to test if people felt more threatened by the same device that they had already co-existed for over 6 months just because of an obviously snoop-suggesting application that ran on it. This application has no user input or interaction. We were interested in seeing whether the prior adaptation period could help to overcome the fear and resistance of deploying a dense imaging sensor network like our UMP system.

Fig. 8. Mirrored Image Playback.

IV. RESULTS

Our results were collected by counting the registration data packets sent from each UMP, allowing us to assuage the percentage of active nodes that were not turned off by building occupants. Figure 9 is a plot of operating UMPs versus hours in a day. Each curve is a diurnal average of the UMP's duty-cycle across the duration of each application (listed in the legend) across our 8-month experimental period.

We can see that Cloud of Images had the highest acceptance – with UMPs operating over 70% of the time. The second most popular (> 65%) application is RSS feed display. The only application that had an obvious daily structure was the Awareness App. We can see from the graph that during the course of a typical day, the average percent of operating nodes changed significantly between 9 am and 3 pm, with a significant peak in activation from 12 to 1 pm. Our speculation about this is that during those hours when the nodes were turned on (12 to 1 pm), people were looking for lunch and may have turned on the nodes to search for social events in other parts of the lab - some users regularly used this application to find their friends and browse activities inside the building. On the other hand, people did not want to be spied on during their working hours. The Awareness App gave users full access to all functionalities, making it hard to control information flow when the nodes were left on. Of all four applications, the Mirrored Image Playback had the lowest acceptance (less than 50 %). The intriguing part is that, unlike the Awareness App, other users cannot access the local video stream. Only system administrator had the power to access any information remotely (data was being acquired for a project on labeling captured video with wearable sensors [8]. Also, as it was deployed 6 months after other applications; the adaption phase should not affect user behavior. This result indicates that application design and presentation can indeed have a strong influence on users' attitudes towards such potentially invasive systems.

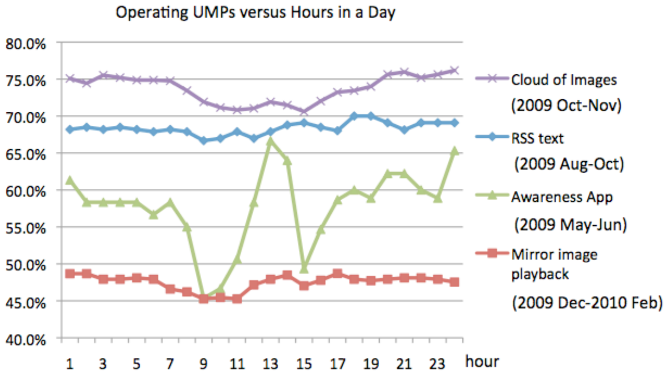
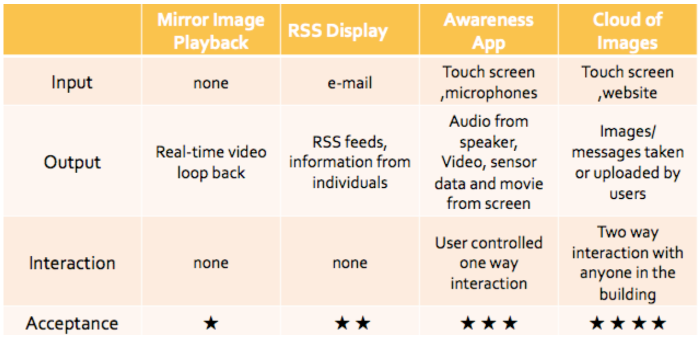


Fig. 9. Average percent of operating UMPs versus hours in a day.



	Mirror Image Playback	RSS Display	Awareness App	Cloud of Images
Input	none	e-mail	Touch screen ,microphones	Touch screen ,website
Output	Real-time video loop back	RSS feeds, information from individuals	Audio from speaker, Video, sensor data and movie from screen	Images/ messages taken or uploaded by users
Interaction	none	none	User controlled one way interaction	Two way interaction with anyone in the building
Acceptance	★	★★	★★★	★★★★

Table. 1.Comparison of the input, output, interaction and acceptance of each application

Table 1 summarizes the input, output, interaction and acceptance of each application. Mirror image playback gives user no interaction. Worse, it creates a fear of the system as a surveillance camera, whereas RSS Display provides useful information and limited interaction. The functionality of sensors is not emphasized. Awareness App gave users full access to all functions of this system - they can request sensor data streams from touch screen input without asking permission from the other end, creating more privacy risks than Cloud of Images, where all the images were taken after the consent of button pressing.

V. CONCLUSIONS

This paper introduced issues encountered when deploying a potentially invasive sensor network as a building-wide infrastructure for various applications. The challenge was not simply the complexity of building and maintaining the hardware and network system. A potentially invasive sensor network, like the UMPs described in this paper, can incite real and inferred privacy risks for general building occupants. Therefore, one of the greatest challenges in sustaining an acceptable deployment is to create a balance between acceptance, system functionality, and perceived value to the building's occupants. Our results, collected across an 8-month study, indicate that applications allowing sufficient, transparent interaction and providing generally useful information are effective ways to increase the percentage of nodes remaining on. Our results can inform the design and deployments of future ubiquitous sensor systems, including those that explore ubiquitous Cross Reality applications.

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