Interactive System Design: Innovative User Interfaces

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Master's Thesis

Digital Culture

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Tiivistelmä – Abstract

English:

This thesis focuses on innovative interactive systems design using a multi-disciplinary approach. The research is rooted in the field of human computer interaction (HCI) and involves aspects of design process through research in human factors, social aspects of interactive systems, and interactive user studies. The prototype systems mentioned in the various papers push the boundaries of user interfaces from the traditional paradigms and seek to provide more meaningful connections with the user and enable positive interactive experiences. By conducting a wide array of user studies, the user centered design process will continue and more efficiently lead to the development of interactive systems that not only meet the usability needs, but are also engaging and fun for the users. This research also helped to bring forward to the design team cultural issues of the user experience and also illustrated the issues of designing for disabilities.

Suomeksi:

Maisterin tutkielmani käsittelee innovatiivista vuorovaikutteista ohjelmasuunnittelua käyttäen monitieteellistä lähestymistapaa. Tutkimus perustuu vuorovaikutteisen teknologian kenttään, ja sen kohteena on suunnitteluprosessin eri osatekijät, joita tutkitaan niin käyttäjään, interaktiivisten systeemien sosiaalisiin tekijöihin kuin interaktiivisiin käyttäjätutkimuksiin liittyvän tutkimuksen avulla. Lukuisissa artikkeleissa mainitut prototyyppisysteemit työntävät käyttäjäliittymien rajoja perinteisistä paradigmoista ja pyrkivät tarjoamaan mielekkäitä yhteyksiä käyttäjälle ja mahdollistamaan myönteiset vuorovaikutuskokemukset.
Suorittamalla laaja valikoima käyttäjätutkimuksia käyttäjäkeskeinen suunnitteluprosessi jatkuu ja johtaa yhä tehokkaammin sellaisten vuorovaikutteisten järjestelmien kehittymiseen, jotka eivät vain kohtaa käytettävyystarpeita, vaan jotka ovat myös mukaansatempaavia ja hauskoja käyttää. Tämä tutkimus on myös auttanut tuomaan esille käyttäjien kokemuksiin liittyviä kulttuurisia tekijöitä ja havainnollistanut suunnittelun hankaluuksia.

Asiasanat – Keywords	HCI, Human Computer Interaction, UCD, User Centered Design, Interactive Systems, Interface
Säilytyspaikka – Depository	
Muita tietoja – Additional information	

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Acknowledgements

I would like to thank the Mixed Reality Lab, Singapore and all of its members for including me as a member of the team. Professor Adrian David Cheok, Eng Tat Khoo, James The, Roger Tan Thomas and all other members. I would also like to thank my advisors Professor Raine Koskimaa and Kimmo Lehtonen for their help over the past two years. I would also like to extend my sincere gratitude to Markku Häkkinen, appreciation of his sharing of knowlege and his continued efforts to bring about positive change.

Introduction

In selecting a topic for the focus of my studies within the Master's Programme of Digital Culture, I explored various aspects of the current issues in our society and the integration of technology into our lives. The most common recurring theme, which became central to my thesis, is the user and the interactive system interface. The thesis is rooted therefore in the field of Human Computer Interaction (HCI) and involves aspects of design of interactive systems through research in human factors, social aspects of interactive systems, and user studies.

During 2006, I made contact with the Mixed Reality Lab in Singapore, led by Professor Adrian David Cheok. With support from the University of Jyväskylä MA Programme in Digital Culture through a travel scholarship and also with the housing provided by the Mixed Reality Lab, I visited the lab for the first time for two weeks in late May 2006. During this short visit, I was exposed to the various projects underway in the lab and I was introduced to the vision and goals of the lab which seek to steer the direction of interactive media and entertainment technology through the project based exploration of novel user interfaces. The concept of moving away from the traditional mouse and keyboard metaphor and embracing technology in a way that it should support the activities and desires of people was most appealing to me. Then in December 2006, I began a five month research internship at the Mixed Reality Lab which allowed me to work closely with the team members and explore deeply the issues designing interactive systems. In this internship period, I worked with the team and submitted numerous academic papers to conferences and journals. Five of these that were accepted for publication or presentation are the focus of this document. The following sections review the main themes of the work, how the papers relate to each other and overall results that can be derived from the studies in general.

Design of Interactive Systems

All of the publications in this thesis deal with the issues in designing interactive systems and specifically focus on the social and cultural aspects of the interface, as well

as human factors issues and the concept of user centered design. These aspects will be discussed in the following sections.

In the context of these papers, the term "design" is used to explain the process of identifying the needs of the user and then providing solutions to those needs. In many cases, in the interactive media design field, the needs of the user are envisioned by the designer and the prototype is built. The user interacts with the prototype and then further refinements can be made based on the results. It is the re-assessment of the user's needs and context of use which is examined in the papers which also helps the designer focus efforts, understand and push the boundaries of interactive systems.

Social and Cultural Aspects of Interactive Systems

The progression of interactive systems began with the period of dominance of the mainframe, then to the personal computer age, and on to the contemporary period which is still unfolding which is marked by the rise of Ubiquitous Computing. Ubiquitous Computing (UC) is a phrase coined by Mark Weiser and is marked by the notion that the number of computer systems and server-like devices will increase dramatically, but will not take the same form as we are accustomed. The possibilities include embedding computer technology in just about everything, but this increase of technology should become transparent to the user and by connecting the devices together, the use of the devices breaks the boundaries of one system being used by one user and the device becomes part of a network of information devices (Weiser, et. al 1996). Making the environment "enabled" with the many information sources and delivery systems provides for many possibilities in the design of interactive systems. It allows for the user to step away from the old paradigms of the keyboard, mouse, monitor operated by a sedentary operator and to use any activity as an input and to provide feedback to the user in exciting new ways. It is rooted in this research that the included papers explore the interface between the user and the computer system and push the boundaries of the connection between the two.

The Age Invaders system is a clear example of this movement towards UC and using technologies to facilitate interactive systems that support social and cultural activities. The Age Invaders (A-I) system (Khoo, E.T., et. al 2006) recognizes that there

is a gap in the technology usage between the young and elderly in which young people in a family are much more adept and the elderly family members are often excluded because they aren't as proficient. The A-I system recognizes this and places the users in a physical setting with intuitive input and output for the users so that computer familiarity is not needed. Additionally, the design goals seek to provide physical interaction at appropriate levels of exertion for the players and to encourage social interaction. This is addressed in the system's innovative difficulty level adjustments which provide a challenging game experience for all players, yet provides some additional difficulties for the more dexterous players. The paper included in this thesis aimed to analyze the user experience and re-assess the context of use and gather feedback for continued focused design of the A-I system and to substantiate the claims that the system can facilitate engaging interactive experiences with old and young together (Khoo E.T., et. al 2007). The study was carried out using questionnaires, structured game scenarios, user observation, semi structured interviews of the players, and designer experiences in working with the prototype. The data was gathered and analyzed borrowing from the grounded theory approach (Glaser 1998) and looked at all data as contributing to the understanding of the system and the experiences of the users of the game.

The results of the study of the A-I system illuminated strengths of the interactive system, but also helped to point out key areas for improving the interface. These improvements are now being worked into the next prototype iteration and will be the focus of more investigation.

In an even more forward looking design study, the Empathetic Living Media paper presented a novel interactive display which uses living media to establish and maintain a relationship with the user. This new approach aimed at appealing to the culturally learned perception of living things and the empathy that can be elicited by displaying data to the users via living media. The hypothesis was that living media as the vehicle of information would establish a more emotionally meaningful connection to the user than the supposed cold neutrality of traditional display devices.

User Studies and User Centered Design

All of the prototypes mentioned in the papers focus on the use of user centered design as a guiding principle. In this process, the needs of the user, user abilities, and the context of use are studied through models created on paper, or in functional prototypes. These prototypes are evaluated and often discarded physically, yet they help in making design decisions by giving the user a system to evaluate and about which they give feedback. This process can be visualized in the process model as shown in figure 1.

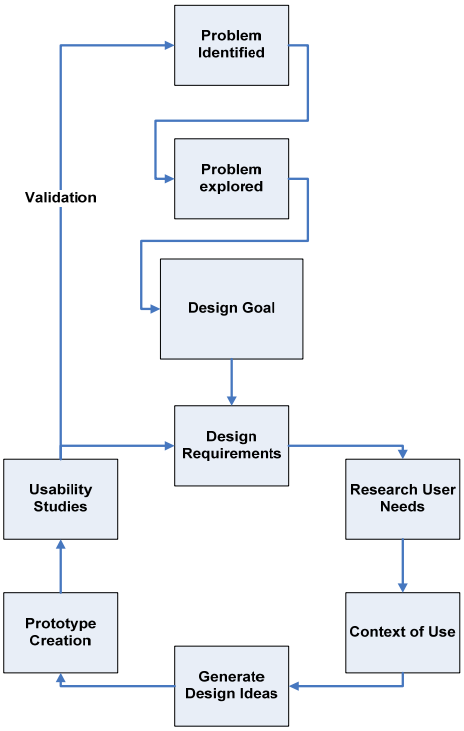

Figure 1: User Centered design process model

This continual involvement of the user helps to understand the functional needs of the system and to validate assumptions of user reception of complex components.
In the *Empathetic Living Media* (Cheok, et. Al 2008) paper, the user studies helped to validate that use of a display using living media would be received well by the users. This type of ambient display system has not been realized before this and so the involvement of the user was critical in understanding which aspects work well and the issues that the user might have with a living display system. We found that the user feels

a more semantically rich mapping of human and ecological issues when this data is knowingly coupled with the living media. In the user studies, we validated this hypothesis and also gained useful suggestions on how to improve the effectiveness of the system. These suggestions included a desire for more color variation, brighter display, and additional forms of the living media concept.

In the *Age Invaders: User Studies of Intergenerational Computer Entertainment* (Khoo, et. al 2007) paper, user studies were central to the study and gave valuable feedback to the design process so that future developments of new prototypes would take into consideration the issues that inhibit good game play and also identify those aspects that already provide for an engaging experience. In the paper, the method of research included the grounded theory concepts borrowed from Barney Glaser (Glaser 1998) and also more structured qualitative data gathered from questionnaires answered by the users. Improvements to the system are now more focused and the design team can be more confident that the voice of the target user in the intended context is revealed. Future prototypes may examine other aspects of the interaction in physical mixed reality, but these new directions for research will be built upon the knowledge gained from this study, giving the design process a better chance at successfully meeting the needs of the users.

The invited presentation at the DIMEA 2007 conference titled *Explorations on Interactive Interfaces Using Cuteness* (Cheok, et. al 2007) presented the interim results of ongoing user studies into the user emotions associated with the interaction with systems that are identified as "cute." The initial explorations seek to isolate the individual variables of an interactive system which the user perceives and to understand what aspects of the variables influence the user's perception of cute. The results taken individually provide direction for future user studies to further explore the concept, but will also help in the design of tangible prototypes of new systems currently in the design process.

In regards to the papers that were a part of the MobileHCI 2007 conference (Häkkinen, et. al 2007) (Merritt, et. al 2007) focused on needs of the user and possible technological solutions to these needs. These papers did not involve direct user testing,

but give background information which will be used in future prototypes. This is discussed in more detail in the following section.

Human Factors and Designing for Disabilities

The field of human factors engineering is rooted in understanding the capabilities and limitations of the user in relation to the tasks or activities at hand. An important component to the study of the user is to consider the capabilities of a wide range of users with varying abilities. Although there are disabilities which affect smaller portions of the general public such as encountered by the blind and deaf, we should consider that nearly all people experience a reduction in the acuity of the senses as part of the normal aging process. In addition to this, there is the concept of situational disability in which even those who normally have no sensory deficiency are not able to function at an optimal level for reasons attributed to the situation. For example, as mentioned in the *Accessibility Issues in Mobile Spatial Audio Interfaces* paper (Merritt, et. al 2007) situations such as user fatigue, temporary environmental changes or simply being a tourist in a foreign location can interfere with a person's ability to perceive and navigate a space.

In the A-I user testing, the elderly users could be considered users with disabilities due to their loss of sensory acuity and limited mobility. In these game studies, it became apparent that many aspects of the prototype should be redesigned to accommodate these user needs. These design changes will likely include the following: increasing the volume of audio game event cues, redesign of the slippers used in the game to be made more securely fastened and adjustable to the individual size, redesign of the handheld game controller to be more intuitive and to possibly provide for multimodal confirmation of other game cues to reinforce the events.

Conclusion

The papers included in the thesis all touch on various aspects of the user and interactive system design. All of the system prototypes represent systems that are on the cutting edge and have not been seen by users on a wide scale. These designs push the boundaries of user interfaces and seek to provide more meaningful connections with the

user and enable positive interactive experiences. By conducting a wide array of user studies, the user centered design process can continue in an efficient manner and more quickly produce interactive systems that not only meet the usability needs, but are also engaging and fun for the users. This research also helped to bring forward to the design team cultural issues of the user experience and also illustrated the issues of designing for disabilities. The interface design projects examined in the papers are all currently in development and will benefit from the multi-disciplinary approach to interactive system design.

Publications Included in Thesis

Cheok A.D., Tan R.T., Fernando O.N., Merritt T., Sen Ping J.Y., Nguyen D.T.K., Empathetic Living Media. Designing Interactive Systems - DIS2008, 7th International Conference, Capetown, South Africa, February 25-27, 2008, *(Accepted and to be published in ACM Digital Library)*

Merritt, T., Sullivan, H.T., Häkkinen, M.T., 2007. Accessibility Issues in Mobile Spatial Audio Interfaces. In *Proceedings of the 9th Conference on Human-Computer interaction with Mobile Devices and Services* (Singapore, September 9 - 12, 2007). MobileHCI '07.

Häkkinen, M.T., Sullivan, H.T., Merritt, T., 2007. Mobile Interfaces for Preparedness and Warning Information: Design Issues for People with Disabilities . In *Proceedings of the 9th Conference on Human-Computer interaction with Mobile Devices and Services* (Singapore, September 9 - 12, 2007). MobileHCI '07.

Cheok A.D., Fernando O.N., Merritt T., Inami M., Inakage M., 2007. Explorations on Interactive Interfaces Using Cuteness. Presentation at the Second International Conference on Digital Interactive Media in Entertainment and Arts 2007 (DIMEA) (Perth, Western Australia, September 19 - 21, 2007). DIMEA2007.

Khoo E.T., Merritt T., Cheok A.D., Lian M., Yeo K., Age Invaders: User Studies of Intergenerational Computer Entertainment. Entertainment Computing - ICEC 2007, 6th International Conference, Shanghai, China, September 15-17, 2007, Springer, Volume 4740, 231-242.

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Cheok A.D., Tan R.T., Fernando O.N., Merritt T., Sen Ping J.Y., Nguyen D.T.K., Empathetic Living Media. Designing Interactive Systems - DIS2008, 7th International Conference, Capetown, South Africa, February 25-27, 2008, *(Accepted and to be published in ACM Digital Library)*

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Häkkinen, M.T., Sullivan, H.T., Merritt, T. Mobile Interfaces for Preparedness and Warning Information: Design Issues for People with Disabilities . In *Proceedings of the 9th Conference on Human-Computer interaction with Mobile Devices and Services* (Singapore, September 9 - 12, 2007). MobileHCI '07.

Khoo E.T., Cheok A.D. Age Invaders: Inter-generational Mixed Reality FamilyGame. The International Journal of Virtual Reality, 5(2):45-50 (2006).

Khoo E.T., Merritt T., Cheok A.D., Lian M., Yeo K., Age Invaders: User Studies of Intergenerational Computer Entertainment. Entertainment Computing - ICEC 2007, 6th International Conference, Shanghai, China, September 15-17, 2007, Springer, Volume 4740, 231-242.

Merritt, T., Sullivan, H.T., Häkkinen, M.T. Accessibility Issues in Mobile Spatial Audio Interfaces. In *Proceedings of the 9th Conference on Human-Computer interaction with Mobile Devices and Services* (Singapore, September 9 - 12, 2007). MobileHCI '07.

Weiser M., Brown J.S., Designing calm technology. PowerGrid Journal, 1996.

Appendix: Published Works

Empathetic Living Media

Adrian David Cheok*
Mixed Reality Lab, NUS

Roger Thomas Kok Chuen Tan
Mixed Reality Lab, NUS

Owen Noel Newton Fernando
Mixed Reality Lab, NUS

Tim Merritt
Mixed Reality Lab, NUS

Janyn Yen Ping Sen
Dept. Biological Science, NUS

ABSTRACT

We describe a new form of interactive living media used to communicate social or ecological information in the form of an empathetic ambient media. In the fast paced modern world people are generally too busy to monitor various significant social or human aspects of their lives, such as time spent with their family, their overall health, state of the ecology, etc. By quantifying such information digitally, information is semantically coupled into living microorganisms, *E. coli*. Through the use of transformed DNA, the *E. coli* will then glow or dim according to the data. The core technical innovation of this system is the development of an information system based on a closed-loop control system through which digital input is able to control input fluids to the *E. coli*, and thereby control the output glow of the *E. coli* in real time. Thus, social or ecological based information is coupled into a living and organic media through this control system capsule and provides a living media which promotes empathy. We provide user design and feedback results to verify the validity of our hypothesis, and provide not only system results but generalized design frameworks for empathetic living media in general.

Categories and Subject Descriptors

H.5 [**Information interfaces and presentation**]: User Interfaces. - Media, Ambient

General Terms

Design, Human Factors

1. INTRODUCTION

We describe a system to use living organisms as part of a novel digital ambient media. Shown in Figure 1, is a living capsule media based on glowing jellyfish and sea pansy DNA inserted into *E. coli* that is capable of making the microorganism glow through the use of our novel closed-loop control system capsule. Social, human, and ecological variables such as interactions amongst loved ones, health, and ecology of ecosystems are translated with meaningful semantics of human's empathy for living creatures through the control system capsule to the organism's glow.

The motivation behind this research is two-pronged. Firstly, to inform, through ambient living media that promotes human empathy, the social and organic happenings around a person's life. Our thesis is that, just as a human prefers to see and receive a living rose rather than an exact replica plastic rose, so too would a living media promote more human empathy about organic based information. Living things evoke feelings due to empathy that are different than what can be evoked by artificial or digital imitations. This is based on the fact that it has been shown that humans have true empathy only for creatures which are alive [12]. Having true empathy is an extremely important way that humans perceive and communicate emotions. Secondly, the use of living organisms to represent the significant portions of one's life adds semantics to the manifestation, since as social aspects such as relationships and addictions thrive and decay, so would the living microorganism. Thus, by tying together digital media with the living world we can develop media that especially promotes empathy about social and ecological information. By taking chosen inputs from social or ecological life, the control system adjusts the fluid flow rate, adjusting the glow of the empathetic living media in real time. For example, our living media literally grows brighter or dimmer according to human social information such as communication time spent with family. By seeing a living ambient representation of family communication time, a person can be encouraged to make more effort to spend time with his children, or her grandmother. On the other hand, a person who has addictions such as smoking cigarettes can be encouraged to make an extra effort to cut back when she sees the microorganisms representing her addiction to tobacco dim in their glow and decay - a very semantically meaningful and living representation of what is happening inside her body. Visualizing this human and social information in the form of fragile empathetic living media places a greater semantic meaning and coupling to the data than non living displays. This thesis was borne out in the user study results which are detailed in this paper.

We hope that by radically exploring into the realms of empathetic living media the boundaries of technology may be challenged, and new waves of innovations may thus be brought forth through the use of other living organisms to create other forms of interactive empathetic living media. It is most important to have an impedance match between the coupling of the input and output of the media. In this case the media is living, and can grow, reproduce, feed, and decay. Therefore we propose it to be tightly coupled with digitally measured information which represents social, human or ecological information such as families, health, emotions, ecosystems, etc. This is outlined in Figure 2.

2. BACKGROUND

There are a few key areas of research that are related to the our living media system and provide key background elements. The first area of research pertains to the user interaction issues. We present examples of related works that engage the user in a manner similar to the design goals of our system. Living media seems

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DIS 2008, February 25-27, 2008, Cape Town, South Africa.

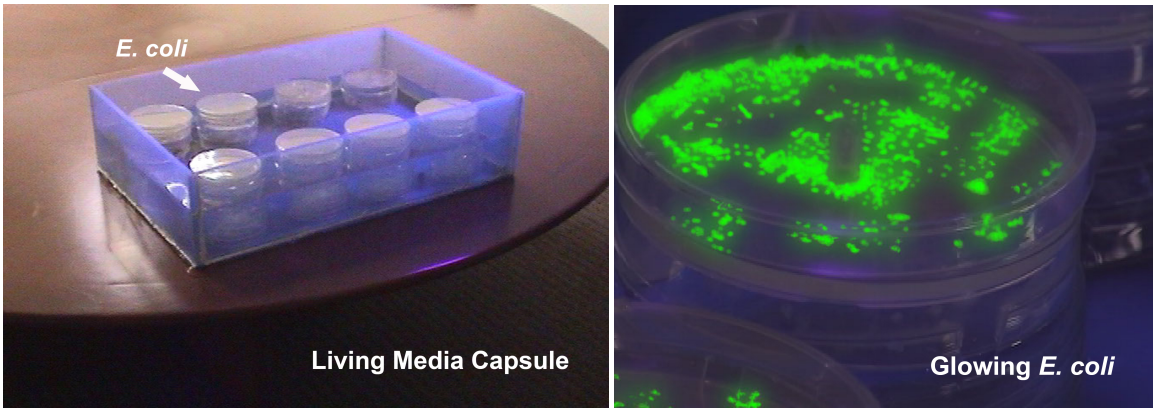

Figure 1: Empathetic living media capsule and close up of glowing *E. coli*

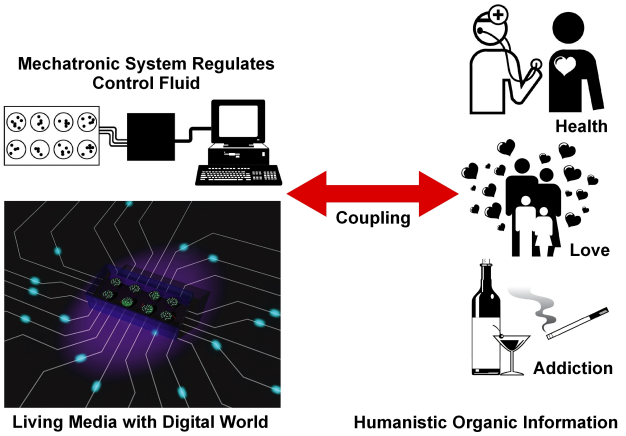

Figure 2: Impedance matching of empathetic living media with humanistic organic information

most appropriate as a peripheral interface which permits the user to engage and bring it into focus as desired. Another key area that supports the system pertains to the research on living organisms. We will present related examples of living organisms which are a kind of media, in the broad definition as an extension of man [9]. In this area we are also concerned with the issues surrounding genetic manipulation and its recent related developments.

2.1 Communicative Ambient Media

People are busier than ever and are distracted and overloaded with more information than they can process. The amount of detailed information available to people is incredible. Researchers from different areas are developing methods to provide the information to the users in more effective ways by appealing to available sensory channels and finding ways to condense the overload of information. Calm technology [14] and ambient media [6] enable different ways to make information available to the user. Calm technology urges peripheral awareness of activity in the virtual world or mediated through the virtual world. Ambient media establishes a connection with the user through altering some aspect of the surroundings.

Example works in ambient and calm media include, the Tangible Bits project [6] (allows users to "grasp and manipulate" the digital information - bits - and be aware of background bits using ambient media in augmented space), ambientROOM [7] (a room that has a range of information displays integrated into its architectural structure), LumiTouch [3] (an augmented photo-frame artifact which allows a remote couple to feel each other's presence and abstract feelings for each other), and Pocomz [10], a communicative ambient display (online status of selected chat pals are displayed in a non-intrusive manner through ambient lighting).

The above systems are all based on electromechanical non living objects. Building on this research, our project uses a non-intrusive biological generated glowing light which has an ethereal quality most suitable to represent abstract social or ecological qualities such as relationships and nature. This can also be used as a means of communication. Adding on to this is the use of living microorganisms which can thrive or decay, hence enriching the semantics behind the fragility of the social and ecological aspects (such as relationships) within the human community that is communicated by the empathetic living media.

2.2 Research Related to Living Media

People have long partnered with living organisms which assist in many aspects of life. We discuss examples relating to living organisms helping man in communicative ways. From the historical perspective, other organisms have served to warn about environmental threats, including water pollution and air pollution. For instance, early coal miners didn't have the special equipment miners have today to measure dangerous methane gas in the air, so they went together with canaries to indicate air quality issues in the mines. Even today, fish are assisting people in the detection of chemical contaminants in public water supplies. For instance, a water security system [16] analyzes the behavior of 8 to 12 Bluegill fish in a tank at the San Francisco Public Utilities Commission's water-treatment plant in Millbrae. Inside the tank, there are instruments that watch the behavior of the fish and can detect the coughing activity of each individual fish. The instruments transmit their findings to nearby computers, which compare the fish cough rates and other behaviors to their normal behaviors. If the computers detect that the fish are upset by something in the water, the system immediately triggers water samples to be taken for further investigations.

I/O Plant [8] is a system that utilizes plants as an input output interface. This is a good example of interaction between nature, humans, and computers.

Various glowing living organisms have been developed previously. For example, Glowing Green Pigs [15], Rabbits ("GFP Bunny") [5], and Transgenic Zebrafish [17] have been made to glow under blue and ultraviolet lighting.

Nonetheless in those cases the genetically-engineered organisms are born with the glowing ability, and the glow cannot be switched or controlled. Therefore they do not represent an interactive media with communication abilities. As for our system, empathetic

living media, the glow level can be computer controlled and hence used to communicate certain information through a digital system. This actually builds on the initial goal of the creator of the glowing rabbit, which is to integrate genetics with communication and interaction, such that the glow displays more than an unconventional phenotype of the organisms, but is used in certain ways which information and data may be passed.

3. THE SYSTEM

As an interactive system, empathetic living media engages the user visually and takes input from various sources. The visual engagement is accomplished through the relative level of light emitted and changes of light level over time. In order to accomplish a controlled system which provides meaningful responsiveness to input, a novel closed loop control system capsule was developed. In the following subsections, we describe the system components and the biological behavior of the empathetic living media to be controlled by the control system capsule.

3.1 Control System Capsule

We have developed a novel control system capsule (see Figure 3) that can automatically control the glow of the bacteria (both for biofluorescence and bioluminescence which will be addressed later). The system operates by carefully adjusting flow of control fluid (Luria Broth (LB) for biofluorescence and luciferin for bioluminescence) in the agar plates containing the bacteria.

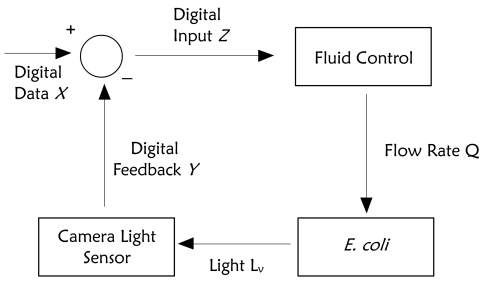

Figure 3: System architecture

As mentioned, the use of Green Fluorescent Protein (GFP) to create glowing organisms has been done before with rabbits and pigs. Nevertheless the core technical innovation in this project is creating a real time closed loop control system to control the LB or luciferin control fluid available to the glowing *E. coli*, and thus controlling the amount of glow. Thus the glow of the living microorganism is computer controlled by digital data. The closed loop control system must operate under high non-linearity as there is non linear relation between the flow rate of LB or luciferin and the resultant output glow. This system is unlike the other glowing living organisms previously created in which the glowing ability is permanent and cannot be changed. Harnessing this ability to control the glow, a communication system is created in the form of ambient media and information is dispensed to users using the glow of living organisms, thus creating an interactive empathetic living media.

The main concept of the control system capsule fashions itself after the biological homeostasis process whereby based on feedback the system is capable of regulating itself. Like any homeostasis process the control system capsule contains firstly a source of input to trigger the process, a source of output for reaction to the input, and a feedback loop to regulate the output source. Based on the requirements of the users, various types of information may be mapped to the empathetic living media through the control system capsule. This information is taken in as a digital input to the control system capsule. Considering the case of communication between loved ones, input data may come in the form of amount of phone calls, emails, and internet messaging between the users. This information is then given to a control system capsule through a simple external workstation. The way of obtaining such information may be through the use of simple protocols much explored in other research [8].

The core of the control system capsule consists of an output module (for activating the glow) and a feedback module (for controlling the glow) both running within the control system capsule. Upon receiving digital input from the external workstation, and the current glow level of the empathetic living media, it reacts by releasing (or reducing) the corresponding amount of control fluid to the plates of empathetic living media. This is done by control of valves connected to supply of the control fluid. A relatively reduced amount of this control fluid will also flow into a relative reduced size dish of *E. coli*, called the control dish, hence activating the feedback module.

The feedback module activates a camera that captures the glow level of the control dish kept within a dark area (note, only the control dish is enclosed in the dark area). This data is then analyzed by the feedback unit and compared to the desired glow level from a preset table of glow levels. Based on the results of this comparison the feedback module will send data back to the output module to increase or decrease release of the control fluid accordingly to reach the desired glow level.

The control system must deal with high non-linearities, as the relations between the input digital data and output light are related through the non linear function of LB or luciferin to the glow of the bacteria. Furthermore the time constants of the various components of the control system (valve, fluid flow rate, bacteria glow change rate) are highly different. To control the system we used gain scheduling control method which use a series of simplified linear controllers [4].

The system was tested and ran robustly in multiple environments (office desk, living room, student dormitory, etc.). The time constant for the change of glowing (as is explained below) ranged from almost instantaneous to approximately 20 minutes, depending on the method of glow that is used.

The next section describes the use of biofluorescence and bioluminescence with further discussion on the control fluids control on the glow of the empathetic living media.

3.2 DNA Altered Bacteria

Using DNA transformation for gene manipulation, there are two types of *E. coli* which give off light. Each has particular qualities of controllability and glow characteristics which we have explored for their use in our interactive system. Our criteria for selection are based on the brightness of glow, the speed of change in glow intensity, color of the glow and controllability of the glow.

3.2.1 Biofluorescence

The first type of *E. coli* that we used was the biofluorescent green fluorescent protein strain which under the presence of a UV light source, fluoresces in the visible spectrum a green color. To be used as a controllable unit of light, the growth of the bacteria is manipulated by altering the nutrient level. The growth and glow of the bacteria is dependent on the LB (Luria Broth) nutrient/sugar concentration, surrounding temperature, and the presence of ampicillin in the agar plates. The nutrients are food source for bacteria; growth is optimal for *E. coli* at 37 degrees Celsius [13]; ampicillin will generate selective growth (i.e. only bacteria

with the ampicillin-resistant gene will grow).

For the use of GFP *E. coli*, the time of change taken for the GFP *E. coli* to regenerate and hence adjust its glow level is about 20 minutes. The control of the glow is a multifaceted process as there are many ways to achieve that depending on the requirements. Generally the glow of the GFP *E. coli* is determined by the amount of LB given. Variations to this may include adjusting the concentration of LB given and volume given.

Furthermore, besides using GFP strands, other colored fluorescence protein strands may be used, like red, blue, and yellow. These colors may be further used to increase the variations in representation. For example the red *E. coli* may be ampicillin resistant but not the green ones. Hence the system could be controlled such that under different situations suddenly the whole living media system will light up red to alert the user of a situation. Besides that the use of multi-colors may be appealing to a certain group of users.

Hence, GFP *E. coli* has a multifaceted control system which also allows it be expandable to handle various intricate human and organic information values. As it may contain other colors besides green and requiring UV light, it may present itself as a colorful living ambient media.

3.2.2 Bioluminescence

Bioluminescence is the result of chemical reactions that produce light in a living organism such as in the insect known as the firefly. One of the possible bioluminescence systems that could be use as empathetic living media is the luciferin-luciferase system which is already well studied and researched [11]. In this system, an enzyme (generally termed as luciferase) breaks down a substrate (generally termed luciferin) with oxygen and energy (adenosine triphosphate, ATP) to produce light.

For expansion on living media with bioluminescence, renilla luciferase, a kind of luciferase, is extracted from sea pansy and inserted into the DNA of *E. coli* such that when the complement luciferin (which is ViviRen in this case) is added to the DNA transformed *E. coli* it will produce light. The reason for choosing ViviRen and renilla luciferase is the availability of modified renilla luciferase which has the ability to react with ViviRen and yet produce light without the need for ATP, thereby reduce the complexity of handling the process.

As this is an enzyme-substrate reaction, it takes place almost instantaneously (less than one second) producing light (seen as white light by the human eye). Control of this reaction is straight forward, by just varying the amount of luciferin given the amount of light energy released may be controlled. Unlike GFP, the effect of varying volume of luciferin has little impact on the glow level as the change (due to the enzyme reaction) is too fast.

Thus as seen, control of bioluminescence is fast and straight forward, making it ideal for applications which require fast reaction time. Furthermore, the use of white light (with no UV light required) may make it appealing for practical use in many applications.

3.2.3 Biofluorescence vs Bioluminescence for Empathetic Living Media

As discussed, both types of DNA altered *E. coli* have their own distinctive glow and glow control. In addition, the biofluorescence *E. coli* costs about 2/3 of the cost of bioluminescence. The differences are summarized in Table 1.

Comparing the two it would seem like bioluminescence is an easier and more straight forward empathetic living media to implement while giving a faster reaction time. Nonetheless it would be noted that for certain users the multiple colors available with the biofluorescence may be a desirable trait. Another possibility is to use a combination of both types in an empathetic living media system.

	Biofluorescence	**Bioluminescence**
Color	multiple color	white
Control	multifaceted	straight forward
Required Light	UV light	none
Speed of Change	20 minutes	instantaneous
Cost	moderate	moderate/high

Table 1: Biofluorescence and bioluminescence

4. DESIGN APPROACH

In this section we will detail the approach to designing the living media system. At first we describe a user scenario of this ambient interface.

4.1 Scenario of User Experience

With living media, the soft glow of the DNA transformed *E. coli* under ultra-violet light could firstly be placed in the relaxing setting of the home or office to give information, without intruding, in an atmospheric manner. Each of the soft glows corresponds to a social or ecological issue of interest to the user such that the glow level of the *E. coli* tells the user the current situation of the human issue.

Such soft glow is capable of staying in the background of the home or office in an ambient manner, merging seamlessly with the background. Such information thus does not demand attention while settling into the environment. Besides being an ambient media, the watch of soft glow that is living gives a calming effect to the user; the feel of a media which is alive yet controllable by the user herself presents a fragility in the life of the *E. coli*. This may not just calm the user but make the overall experience more enriching.

Secondly the use of living organism to dispense social or ecological information maps effectively the semantics of the information. A working wife seeing how communication with her husband is dimming like the glow of the living *E. coli*, may just decide to leave office earlier for the day and spend a nice Friday evening with her husband. A smoker seeing the glow of living *E. coli* slowly decaying may make him realize that parts of his lungs are actually decaying too and eventually embark on giving up his smoking addiction. In an office, a wall display of empathetic living media which is mapping to the growth or decay of rain-forest in South America would constantly remind all of the fragility of our earth's environment.

We have designed a design language for various applications. We believe one "bit" would be able to provide clear communication due to the analog level of glow. For example, for a family communication system, the empathetic living media would be placed next to photographs of family loved ones, and then hang on the wall or placed on a table top.

The coding of the empathetic living media in this case would clearly show the communication (measured by number of calls, messenger chats, emails, etc.) one has with the family from the mapping: the higher the glow, the greater the communication. In another application the glow may be used for personal use like measuring one's health in terms of the cholesterol level: the higher the glow, the lower the cholesterol level is. These applications are outlined in Figure 4.

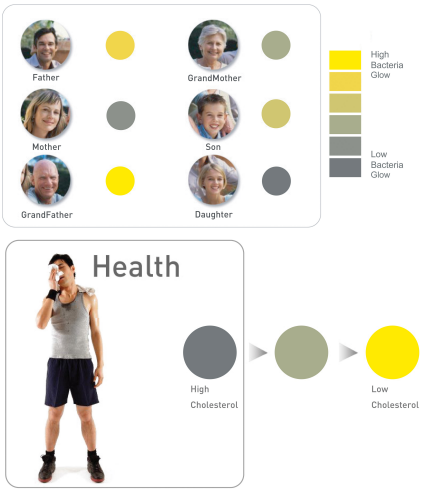

Figure 4: Living media information coding

4.1.1 User Studies

In this research we are designing for a general form of empathetic living media ambient interface. Thus, a careful analysis of the user and the context of use helps to answer questions about features and function of empathetic living media and an understanding of user needs or desires. The examples of earlier ambient systems help to build a case for general interactions using empathetic living media.

In previous projects which involved electro-mechanical systems, the user is fully aware that electronics and logic are responsible for the display of information. As in the Ambient Orb[1], electric lights provide the glow and although the transitions of colors and intensity are gentle, the user is aware of the cold, digital nature of the device. We hypothesized that the users map information differently for empathetic living media. To understand some general aspects of the user opinions, we developed a user study made up of a mix of closed and open ended questions. This study helps to focus efforts in the design and use of the prototype and helps isolate issues that may require more in depth study to understand the user. The questionnaire was focused at answering the main design questions of our current system. The questions are presented below with our hypotheses as well.

In this study, users experienced the empathetic living media system by observing two forms of empathetic living media capsule (Figure 1) for one working day in an office setting. One of the capsules used biofluorescence and the other used bioluminescence *E. coli*. In order to conduct similar tests for each user, the data that was input to the display was identical pre-captured data for each test run (however, apart from this, the system was running live and in real time). One set of data corresponded to the number of chat messages per hour between two friends to provide an example of social communication. The other set corresponded to the pollution index of Singapore air to provide an example of environmental data (the data was compressed to represent a 1 month period to be shown to the user in one day). The biofluorescence display was used to indicate the pollution index, as the time constant of the display is approximately 20 minutes, which is suitable for slow changing media. The bioluminescent display has almost instantaneous change, and is therefore suitable for displays of real time social communication, such as our chat message data.

An example of one of the experiments with participants using the ambient living display on their office desk is shown in Figure 5.

[1]http://www.ambientdevices.com/

Figure 5: Office workers with empathetic living media ambient display on desktop

Part of the user feedback is to compare exactly the same visual display in both living and non living form, to determine if there is any difference in the empathetic feeling for the data by the user. In order to do this, the user was presented with an application which would run on their computer. The application contained a 3D virtual reality version of the empathetic living media capsule display which was fed by the same data. To a good approximation (although not exact, as it is almost impossible to exactly model the real time glow of the living bacteria), the virtual reality version presented the same visual display to the user, except it is in purely digital form. An example of the user running the virtual desktop version can be seen in Figure 6.

Figure 6: User seeing digital version of living media on personal computer display

The user was instructed as to the nature of the data in each display, as well as the time constants involved. The user was informed to observe the display in their office, but to carry on the normal day to day office activities, since the display is meant to be and ambient and used in the background. After the one day experiment, the users were asked multiple questions.(Note: only some questions are shown here due to space restraints.)

As part of the administration of the study, the respondents also watched a video with explanation of the empathetic living media project. Additional verbal explanations were given to explain the concepts of ambient media, calm media, and empathetic living media. As part of the explanations, the respondents were given the paper about Pocomz [10] and were asked to consider this type of media as an example of calm, ambient media. This served to help the respondents develop opinions about the genre and to provide more meaningful input regarding their acceptance of the technology.

4.1.2 User Study Questions

The user study questions and hypotheses pairs are as follows:

1. *User Acceptance of Ambient Media*:
   Question: How do users feel about ambient media?
   Hypothesis: Users will generally enjoy the idea of ambient media and express desire to have interaction with ambient media in their everyday lives.
   Example Question: "Do you think ambient media systems would be useful for you?"

2. *User Acceptance and Preference of Living Media*:

   (a) *Acceptance of System*
   Question: How do users feel about living media and what emotions are associated with the system?
   Hypothesis: Users will generally enjoy the idea of living media and express empathetic emotion for the media.
   Example Question: "Considering the test do you think living media provides more empathy for the representative data?"

   (b) *Preference for System with Regards to Empathetic Feeling:* In this part of the experiment, we wish to determine if the same visual display in living and pure digital form would result in any different empathy from the users.
   Question: Which would users feel more empathy for: living or non-living versions of empathetic display that presents the same data?
   Hypothesis: Users will generally have more empathy for living media over non-living media. Presented with both living and non-living media versions of the empathetic display with the same data, the former will be more opted for as it will produce more empathy for the same data displayed.
   Example Question: "Given both living and non-living media versions of the empathetic display with the same data, which version did you feel more empathy for?"

3. *Ambient Media Information Mapping*:
   Question: What issues are appropriate for ambient information systems?
   Hypothesis: Users will find social or ecological issues that are meaningful to their lives appropriate for ambient media information systems
   Example Question: "Do you think that ambient media can be effective in helping people to quit a bad habit? Please describe examples of how it might be used."

4. *Living Media Information Mapping*:
   Question: What issues can be represented with living media specifically?
   Hypothesis: Users will show preference to displaying emotionally engaging issues through living media and will provide more examples of using living media as ambient information systems versus non-living media.
   Example Question: "What social or ecological issues would you like to see used in the project?"

5. *Prototype Acceptance*:
   Question: How do the users experience the prototype and the idea behind the living media design?
   Hypothesis: Users will show positive response to the aesthetics and semantics involved in the prototype.
   Example Question: "Knowing that the media is a living organism, how strongly does the brightness of the glow affect the acceptance as a media display?"

6. *Other Applications*:
   Question: How do users feel about other kinds of living media?
   Hypothesis: Users will be delighted in knowing other novel ways to display information and will show a preference for the living media.
   Example Question: "Assuming there is a type of fish that can be used as a empathetic living media. It changes color very quickly and using control systems, we can provide an interactive display. How do you feel about fish as an empathetic living media?"

4.1.3 User Study Results

Our study was conducted on 31 participants. These participants ranged from 16 to 39 years of age, with the largest group (41% of the group) being between the ages of 21-25. Slightly more than half (56%) were female, and the occupations of the participants included engineer, administrative assistant, accountant, teacher, manager, salesperson, and student. For those who did not have offices such as students, the display was placed on their lab table.

User Acceptance of Ambient Media
Almost all users (91%) provided feedback that they find ambient media useful. Only one respondent was unsure if they themselves would find it useful, but that respondent expressed a desire to try ambient living media on a longer term basis to help make the decision.

User Acceptance and Preference of Living Media
The respondents quite strongly (85.6%) supported the idea of living media as being useful. Likewise, the responses showed a slightly stronger opinion that living media would be well received by others when asked to decide which type of display would be most suitable for conveying social or ecological information. We further tested the user opinion in the *Prototype Acceptance* section for user preference.

With regards to comparing the exact same information presented in the same format visually, except that one was living media and another was purely digital media, most of the users (87.3%) felt more empathy for the living media version of the display. As the data was related to human and environmental data, the living media is able to produce more empathy for the data. Hence, empathy is felt more by the users of the living media.

Ambient Media Information Mapping
The users showed a strong acceptance (83.8%) to having the information mapped to human issues and ecological information related to the environment. Similarly, a majority (85.6%) users chose to have the personal information displayed in symbolic representation and also a strong desire (81.1%) for information to be displayed in pixel form. The combination of these two also showed high user acceptance (83.8%). Colors seemed to be a recurring theme for most users and surprisingly, the range of colors associated with emotions varies considerably. While we can presume that the users can learn a color to a meaningful relationship, the personalization of the system may be an added feature to consider (such as mapping red to a loving relationship).

Living Media Information Mapping
The respondents again chose mapping of humanistic and ecological issues. Some users (12%) also mentioned that living media in the form of plants gives the idea of self sustaining operation which gives a unique aesthetic. Future plant living media can help to study this mapping further.

Prototype Acceptance
The respondents showed interest in the look of the media. There

was a unanimous desire for the media to be as bright as possible. A few of the users (27.9%) reported that not "seeing the wires" adds a nice aesthetic appeal and enhances the warm, living nature to the media. Many users (67.6%) also expressed a desire for the media to glow in multiple colors. We are also looking into this as a feature in the next iteration.

Other Applications
In this section, we solicited the opinions about other planned living media. The response was overwhelmingly positive in the desire for other living media such as plants and fish. Most users mapped environmental and personal issues to living media which helps to confirm for us that this is a natural association. Although living media can be used to represent stock market data, it seems to be more easily associated to the issues of living and indicators of environment.

5. LIVING MEDIA SYSTEM DESIGN PATTERNS

This research was not aimed at only producing a working prototype, that can be used in home and office environments, but also through the design and experimentation to construct wide issues of design patterns and frameworks for new types of empathetic living media that can be used by the media interface designer. Besides obtaining user feedback and experience as an input in the design process, formal qualities of existing empathetic living media systems can be analyzed as well. A taxonomy emerges of design archetypes of living media. This benefits future designers of living media going forward, by helping to locate the proposed system in the existing landscape and quickly identifying varying aspects. This also helps designers to see which design patterns are mainstream or underrepresented. The systems available and included for this study are: I/O Plant, Transgenic Zebrafish, GFP Bunny, Glowing Green Pig, Bluegill Fish, and Living Media. Six design dimensions based on observations of these mentioned living media systems are presented:

Organism: The organisms used as the living media do play a part in the overall effect of the system, since based on the nature of the organism, certain organisms do have different effect on people. For example considering plants versus animals, seeing a moving animal may affect a person differently as compared to seeing a stationary plant. Organism in this dimension is split into three categories - prokaryote (for micro-organisms), plants, and animals.

Interface: As a media system, the way it presents itself and allows interactivity with the users is important as well, this makes the interface one of the selected dimensions. Based on how living organisms interact with human naturally, various possible means of interaction for living media are considered and categorized as - smell, movement, sight, touch, and mix: a mixture of different means of interactions.

Control: As a media system would the user be able to control the media and to what degree of control does it offer? Such controls could be - user based, non-user based and no control at all.

Time Constant: As a media system would the system be able to react in real time or over a period of time accordingly to users' input. Such time constants could be - Short, Mid, Long, and None (to indicate that the system does not respond and is not controllable at all).

DNA Alteration: Some of these existing living media systems are DNA altered (like the GFP Bunny) while others are not. Hence this dimension's categories are - Non DNA altered, Localized Manipulation (meaning only a certain part of it has its DNA altered after birth) and Embryonic Manipulation (meaning the DNA was altered such that the organisms is born with the genotype such as the Transgenic Zebrafish).

Semantics: The semantics behind the use of the living organisms as a choice for living media. The possible categories are - No semantic mapping, Mid semantic mapping, and High semantic mapping.

The systems chosen are ranked accordingly to the information as obtained from published conferences and journal papers as well as official websites of the systems. These systems chosen are not intended to be an exhaustive listing of all living media systems, since while having an exhaustive list give completeness it may not be required for the development of a living media system design framework.

Figure 7 shows the six dimensions for the analysis. Colored lines trace the positions of systems on each axis while each axis is categorized into its different categories. Based on the clustering of systems, four design patterns for living media system (after pattern language for architectural studies [2]) are thus obtained. These four archetypes are: Inherent Phenomenon, Semantic Interaction, Functional Transformation, and Transgenic Display.

Inherent Phenomenon accounts for I/O Plant and Millbrae Bluegill Fish. The prominent feature of this particular archetype is that the living organisms used are non DNA altered. The organism's features used as the source for the living media is an inherent phenomenon, like the Millbrae Bluegill Fish which inherently cough to alert of unusual findings in the water. Such systems revolve around making use of certain inherent traits of the organisms to create a form of media.

Semantic Interaction accounts for our Living Media system. The prominent feature of this archetype is the interactivity available that is mapped to certain semantic values. The organism's feature (which is DNA altered) may be changed over time as controlled, and this change is a semantically representation of a certain value of interest to the user. Such systems intend to create meaningful interactive media through semantic mapping to various possible living medias.

Functional Transformation accounts for Transgenic Zebrafish. The prominent feature of this archetype is the unconventional phenotype of the organisms (obtained through DNA alteration) used to fulfill certain functionality. Like the Transgenic Zebrafish, containing genes from jellyfish, will change color to notify of pollution of the water. Such systems transform embryonic DNA for creating useful functionalities.

Transgenic Display accounts for GFP Bunny and Glowing Green Pig. The interesting feature of this archetype is the unconventional phenotype of the organisms obtained through DNA alteration and used for display. Such systems are aimed at altering DNA of living organisms to create unconventional and interesting phenotypes for artistic or other novelty purposes.

While the four presented archetypes can help designers in future design, it does not represent the only possibilities for building such systems. More importantly will be the use of the six dimensions in consideration of a new design. There could be various possibilities through different mixes of the categories within each

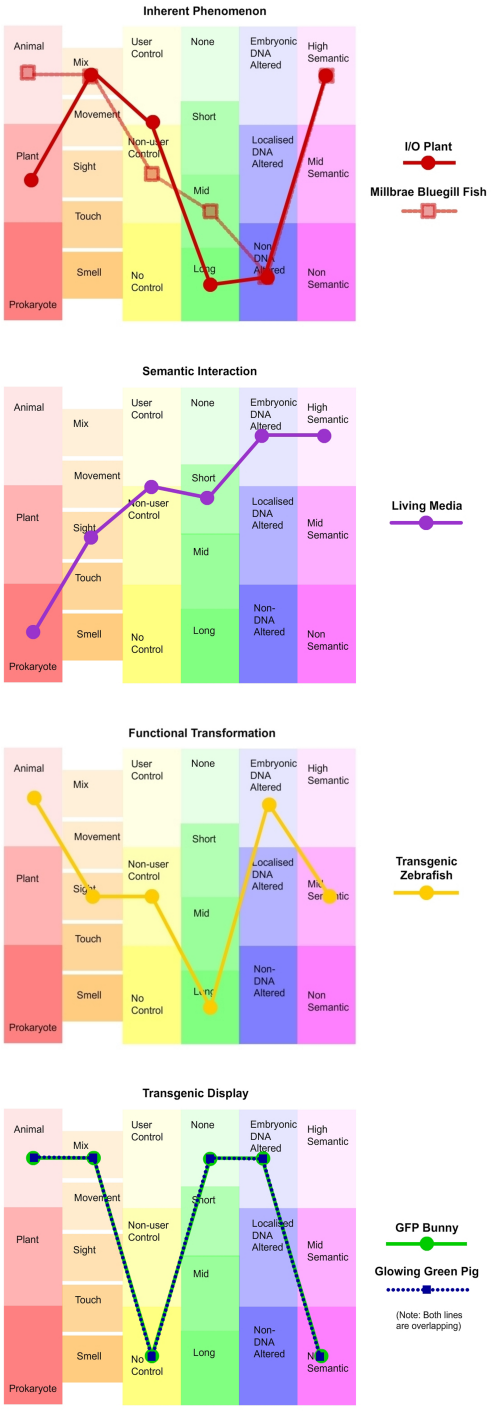

Figure 7: Design patterns for living media. The six dimension axes from left to right are organism, interface, control, time constant, DNA alteration, and semantics.

of the six presented dimensions. For example, it may be interesting to create a plant which interacts by emitting various smells according to the mood of the user to create certain ambiance within the room.

6. FUTURE WORK

The implication for this work is that it provides a new way of communicating information, through ambient displays using empathetic living media. It is expected that the work of this project shall trigger a new research area in interactive living media. At this stage there are no other examples of interactive living media which controllably changes glow and color with time, hence this project may create a new area for exploration and commercial products for interactive living media.

A new domain of empathetic living media could be expected in the future. We are planning to produce an expanded field of other empathetic living media that could be extended from the research knowledge gained from this project. It should be carefully noted that any work carried out in this area now, or in the future, must be done in full consideration of ethical issues, and in consultation with philosophers, psychologists, and the general public through user studies. All the work we have conducted was carried out with approval by our university's Institutional Animal Care and Use Committee (IACUC). Researchers worldwide similarly should comply with their relevant authorities. However, in general, the USA Animal Welfare Regulations [1] gives good guidance to this new area of research.

Thus, based on the above ethical considerations, we have ideas for new types of living media. Most are speculative only and before we create them, we will seek full ethical and legal approval.

Squid Phone A pet squid which changes color accordingly as the user is contacted by only very special friends or family. This not only informs the user of the important phone call or message, but at the same time adds to the ambient display through use of living media. The living squid changing color immediately gives the importance of the living information related to one's close family or friends.

Social Activist Fish Arts Based on Transgenic Zebrafish developed at the National University of Singapore [17], we aim to create beautiful color changing fish which will be a living form of social activist art. For example the fish colors could change according to the number of living endangered species such as panda or tigers, number of HIV deaths, birth or death rate of populations. Not only does the organic humanistic information couple with the living fish media, but it will create an ambient message for social activism in an artistic manner. For instance, "The number of Panda Bears still living in the wild" or "Number of people in the world dying of smallpox" or any other global issues that interest specific individuals.

Handy Crisis Digital communication devices are becoming broken due to overload and intrusiveness. For example, many people have no time to respond to email, and often turn off their mobile phone. However, with our most personal and close loved ones we would always want to be in touch, no matter where in the world. Thus we envisage very personal and body transforming communication such as "Handy-Crisis": In cases of emergencies like loved ones being hospitalized a certain designated portion of the hand may glow to notify the individual of the crisis.

Color Changing Cabbage Red cabbages may be used as living media by inserting electrodes into them to control the level

of negative electrons and hence the level of positive hydrogen ions within the red cabbages which may then causes change in the color of the red cabbages accordingly. This may be used in a cabbage patch, where the cabbages may change color accordingly to the weather, letting the farmer know about the weather forecast. It could also be used as a beautiful home living ambient media, with cabbages laid out in rows similar to pixels.

Ant Interface Insects are gathered into groups using the pheromones of attraction. These groups together make pixels in a grid like display. The user provides input by taking pictures with a camera. These images are rendered with the parade of ants.

7. CONCLUSIONS

Empathetic living media is the revolutionary system that enables the use of living creatures as a controllable ambient display. Information based on human and natural information is quantified digitally and communicated in the form of ambient display by computer controlling the glow of living *E. coli*, thus creating a novel media that is alive. This display shows significant organic and human aspects of an individual life, ecology, or society and enriches the semantics between mapping of the living organisms to such considerations. The control of this display is achieved with a closed-loop control system which monitors the flow of a control fluid to modify the glow of the empathetic living media. This glow is in turn regulated with a feedback unit that captures the intensity of the glow for feedback purposes. By conducting user studies, we have confirmed that users are receptive to ambient and living media and we have gained an understanding of the features desired. The preference for empathetic living media over non-living media to represent human issues was demonstrated. The benefits of appealing to the empathetic emotions of the user help to make an interface that shows promising possibilities as a technological tool for motivation, relationship maintenance, and environmental awareness. This research was not aimed at only producing a working prototype, but also through the design and experimentation results to construct wide issues of design patterns and frameworks for new types of empathetic living media. These can impact in general for the benefit of media interface designers.

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Accessibility Issues in Mobile Spatial Audio Interfaces

[Moving Spatial Audio out of the Lab and onto the Street]

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ABSTRACT

Spatial audio is of special interest to people with disabilities, in that auditory cues can provide useful information about location of places and important issues of interest within an environment. Spatial cues can be reliably presented in fixed locations or where instrumentation is available so that the user's orientation within an environment is known. But in an arbitrary mobile context, spatial audio cues are more challenging, given that it may be difficult to determine where the user's point of view is oriented. This paper discusses the challenges of spatial audio for those with visual disabilities and presents promising avenues of investigation from the context of disaster preparedness and evacuation wayfinding.

General Terms

Spatial Audio, Visual Disabilities, Non-visual Navigation

Keywords

Wayfinding, Emergency Preparedness

1. INTRODUCTION

For people with visual disabilities, spatial audio provides a useful mechanism for presenting information about the unseen, whether it be the location of a specific object in the environment, a pathway to an exit, or indication of an obstacle in the path of travel. Reliability of the spatially presented information is of particular importance; if the auditory cue erroneously indicates a passageway at the user's 2 o'clock position and it is really at 3 o'clock, a collision with a wall may result. Spatial audio applications, to be effective in providing environmental location and wayfinding, must have a clear model of the user's orientation and point of view within the environment.

Traditional spatial audio and virtual environments make use of position sensors to determine the users point of view. With point of view known, spatial cues can be presented in the correct orientation and can be tracked within the environment as the user's point of view shifts. In arbitrary mobile contexts, this becomes a more challenging problem. In the following sections, we discuss the challenges for the user with a visual impairment. We then explore some approaches to the use of Spatial Audio intended for people with visual disabilities. We then bring the focus of the discussion to the scenario of emergencies in the public space and review approaches to assistive spatial audio technologies. Finally, we provide concluding comments that will stimulate open discussion for the the Workshop of Spatial Audio for Mobile Devices.

2. CHALLENGES FOR THE USER WITH VISUAL IMPAIRMENT

People with a visual impairment face significant challenges in navigating a world which is dominated by text, visual symbols, and interior and exterior public spaces that wayfinding challenges. In many public places around the world, textured surfaces are incorporated into floor tiles and sidewalks as a wayfinding aid for the visually impaired [1], providing some independence with respect to movement within built environments. However, not all public places are able to be outfitted with the textured tiles, and the complexity of some environments, such as an airport or subway station can be challenging to the user. In the case of temporary obstacles (construction) or the more critical case of emergencies with resulting congestion, the person relying upon the physical aide is at a clear disadvantage.

Individuals with visual impairments often compensate for the loss of the visual channel through greater attention to, and use of, environmental audio cues. Binaural hearing allows for a three dimensional interpretation of a space, with the acoustic environment providing a rich field of active and passive cues. Auditory cues are now commonly found at pedestrian crossings, indicating to the visually impaired and sighted alike whether it is safe to cross a street. Most public environments are saturated with ambient noises and therefore, most public auditory aides can only serve as a rough beacon, guiding users to one location. This impersonal assistance is not particularly useful to the users with varied needs and certainly in the time of emergency, the beacons could be confusing and may misdirect users in a time of need.

Mobile technologies offer the opportunity for individually

directed messages and navigational assistance. Though we find research and application of spatial audio for training and familiarization of real and virtual environments, at the present time, there isn't a widely implemented system using spatial audio and mobile devices for people with visual impairments [2].

3. CURRENT APPROACHES TO AUDITORY NAVIGATION

A review of some auditory assistive technologies is worthwhile to describe the basis of our current focus. We now discuss assistive technologies for virtual space of electronic and hypertext and mobile navigational systems using spatial audio.

It would be appropriate to note that much of the standards-based developments of spatial audio for the Web was evolved from research by Raman [7], who developed ASTER (Audio System for Technical Reading) as a tool to non-visually explore mathematical equations using 2D audio.[1] used 2D spatial audio to allow navigation of mathematical equations. This initial work lead to basic 3D audio extension to Cascading Style Sheets (CSS) [8] and subsequently to the Speech Synthesis Markup Language (SSML) [9]. Extensions to the Synchronized Multimedia Integration Language (SMIL) [10] have also been periodically proposed.

The aural capabilities of CSS defined a mechanism to place sound sources in a 3D space (azimuth and elevation). The CSS2 aural properties are included in the Speech Synthesis Markup Language. There have been several research implementations of the CSS 3D features (e.g., [11]), though none of the major Web browsers currently support these features. Wider support of these W3C standards within the mobile device community could do much to facilitate adoption of spatial audio applications.

In regards to navigation in physical space, Touch Graphics, Inc. [2] [3] used a mobile phone within a museum exhibit hall to provide orientation for visually impaired visitors. A mobile phone is used to dial the number of an exhibit and an auditory beacon would signal the location of the exhibit, serving as a wayfinding guide. People with visual impairments are already accustomed to environmental audio cues, such as crossing signals, and entrance beacons. Because these cues are nonspecific to an individual user, such cues are only able to serve as general beacons and are heard by other museum goers.

Talking Signs [4] is another concept that has seen research and some implementation. This approach provides the visually impaired user with an infrared receiver with audio output. Specialized signage which emits a coded infrared signal is installed within a physical environment. As a user approaches the sign, an audio description is presented.

The use of 3D sonification for exploration of city maps is proving successful as a tool to familiarize a visually impaired person to a new environment [5].

Massof has reported on "Auditory Flow Fields" that blind people have described as a way to navigate and interpret the environment [2]. In his work, Massof mentions that there is a missing piece in the assistive technologies for auditory navigation, with no assistive devices that use both 3D sound and sonification. Though there have been a number of GPS-based tools, such as Trekker 3.0 [6], developed to provide visually impaired users a means to navigate their environment using GPS guidance using verbal cues, the transition to use of spatial audio to real time navigation remains as a challenge.

4. APPLICATION OF DEVICE-BASED SPATIAL AUDIO FOR EMERGENCIES AND EVACUATION

Can mobile device-based spatial audio provide value in the critical context of Emergencies and Evacuation? We can strongly suggest that for environment familiarization training (the non-realtime exploration of a virtual version of a real environment) mobile devices may have significant value. A personalized, headset model (the user is in their own virtual audio space) offers privacy and training options not possible with the auditory beacon approaches described earlier. In this case, the pings are personalized and only heard by the intended user. From an emergency preparedness perspective, we know that rehearsal (practice/training) is key to effective evacuation (or disaster response) and a personalized approach allows a visually impaired individual (or anyone who might benefit from an auditory presentation) to examine wayfinding without impacting the auditory environment of others. A visually impaired user can enter a new environment, and receive, either via download or streaming, a virtual guide to the physical space. As a realtime navigation aid, a form of augmented reality in which landmarks (or evacuation routes) would be spatially announced, the question of user position and orientation is critical. The question of how spatial audio cues be used on mobile devices to reinforce to the visually impaired person that there in fact is an emergency and where to go to evacuate or obtain more information is an area in need of more research.

4.1 Directing Attention

A key challenge we find is the idea of synchronizing the users position in a physical environment to the virtual spatial audio version of the environment. What approaches can be taken to direct the users attention to a point in space, and then synchronize the spatial audio presentation to a known point of view? We suggest there is a need to examine the feasibility of using a combination of the auditory beacon approach and spatial audio to draw the users' point of view to a known direction, thereby facilitating presentation of a virtual sound space matching the users orientation. It should be noted that in large public spaces, we might find that there are multiple people with visual impairments present and that activations of multiple orienting beacons could lead to potential confusion.

Another approach can be modeled after the configuration of information kiosks designed for the visually impaired that are found in many Tokyo subway and rail stations. In Shin-

[1]T.V. Raman's personal website can be accessed here http://emacspeak.sourceforge.net/raman/

[2]Touch Graphics, Inc. and the project details can be visited on the web at http://www.touchgraphics.com/ping!.htm

juku station, near the Keio exit, there is a kiosk which has an active audio beacon and raised textured guideway tiles on the floor leading to it. This multimodal set of audio and tactile cues helps to confirm to the visually impaired visitor that in fact they are approaching something worthy of attention and ideally not just another noise in the environment. A promising approach may be to explore the use of haptic and audio cues that can be triggered on the mobile device of the user to provide further guidance and an explanation of the services available at the kiosk (information, ticketing, assistance, etc). Another approach, where kiosks may not be available, could utilize RFID tags within traditional wayfinding maps or building directory . A mobile device with a RFID reader can identify the current location (based upon a query of the tag), assuming the user is facing a known location, a spatial audio map of the location could be presented to the user.

5. CONCLUSIONS

As we have shown in the previous sections, we hope to illustrate that spatial audio for mobile devices is a promising avenue for development of assistive technologies for people with visual impairment. We have used the example of emergencies and evacuation as this presents a scenario with a real world impact. We hope that this paper will stimulate discussions on strategies and future works that might help to further assistive technologies. We would also like to invite the readers of the paper to imagine these technologies and their usefulness for those without sensory impairments, for example for those who may not be familiar with the language and signs in a foreign place, and may benefit as well from a standardized spatial audio navigation system.

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Mobile Interfaces for Preparedness and Warning Information: Design Issues for People with Disabilities

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ABSTRACT
Mobile devices can play a key role in disaster warning systems, and are now being incorporated into a variety of emergency notification systems. From the perspective of accessibility, mobile devices present multiple challenges to people with disabilities, affecting those with sensory, cognitive and physical impairments. There has been growing recognition of the problems faced by people with disabilities in times of disaster, and it is critical that designers of mobile solutions for public preparedness and warning understand the unique needs of this population. Attention to accessible design may in turn lead to improvements in general usability of these mobile services. This paper examines some of the issues in accessibility of mobile devices in the context of preparedness and warning applications and discusses the accessible design of mobile warnings.

General Terms
Human Computer Interface, Mobile Devices, Human Factors, Accessibility, Standardization.

Keywords
Accessibility, Public Warning, Disaster Preparedness

1. INTRODUCTION
The use of mobile devices to deliver disaster and public safety warnings is gaining increased interest and implementations, both in the commercial and open source domains[1]. Development of standards such as CAP, the Common Alerting Protocol [2] are facilitating a common means for government agencies to generate messages which can be delivered to a variety of channels. In some locations, such as Singapore, local governments make preparedness material available on mobile phones [3] to augment more traditional materials. Mobile devices are attractive in that they are personal and generally carried on the individual during much of the day, and the expectation is that when an alert is received, the recipient will detect, understand, and act upon the warning.

Many factors, however, can reduce the efficacy of mobile alerts. Looking at the experience of public warning, we see evidence that critical messages can be ignored, not understood, or result in confusion [4]. The reasons why messages may fail to elicit the appropriate action can stem from the design of the message itself, environmental conditions, lack of motivation, or sensory and cognitive impairments. Such failure is now recognized as being largely due to a lack of understanding of the human factor in the design of disaster warning systems.

For one group, in particular, the use of mobile devices poses significant challenges. Approximately 600 million people or 10% of the current global population may be classified as having some form of disability, with 80% found in low-income or developing countries [5]. It should be noted that disability statistics in the United States indicate that up to 20% of the population may have some form of disability or impairment [6]. The figures for the United States suggest a better rate of disability identification rather than a greater incidence relative to other countries, and with that assumption, it may thus be more realistic to consider more than 1 billion people with disabilities globally.

Usability of a mobile device can obviously be limited for people with visual, auditory, physical, speech, cognitive, neurological, and learning disabilities. It should be noted that disabilities can occur alone or in combination, compounding the difficulty faced in using some technologies. Small keypads, small displays, audio signals, and visual interfaces contribute to usability challenges. With the aging of populations, growing numbers of people face age related changes in vision, hearing, dexterity, and memory. It is not difficult to recognize the impact impaired vision, dexterity, and hearing can have on the usability of such devices, especially if they become critical components of emergency notification systems. For example size and type face requirements for an individual will vary over time. As visual acuity diminishes with age, the need for a secondary, non-visual cues may be necessary. The complexity of modern mobile phones offer additional challenges to the elderly as well as people with cognitive disabilities [7] which can limit their usability as a preparedness or warning mechanism for groups with special needs. Learning disabilities, such as Dyslexia, may make it difficult to understand textual information and complex displays.

It is also important to understand that people with disabilities are part of an overall larger group of people at risk who may face challenges in using mobile technologies for emergency communication. This larger group can be termed vulnerable populations and includes the very young, the elderly, immigrants, refugees, and others who may be physically, linguistically, socially, or economically at a disadvantage when it comes to receiving or acting upon preparedness or warning information. We may also expand the concept of the vulnerable population by adding transient members of a community, such as tourists, who may face challenges when confronted with disaster while linguistically isolated and in need of assimilating lifesaving information and guidance quickly when under stress [8]. An

example of this latter group are the large number of vacationing tourists who lost their lives in the Indian Ocean Tsunami, or those tourists stranded while visiting New Orleans during Hurricane Katrina.

Recognition of the needs of vulnerable populations has been growing, and specific identification of preparedness and warning technologies as problems areas has been reported. The World Summit on the Information Society in 2005 included mention in the final documents that populations with special needs must not be excluded from the use of ICT, and specifically mentions ICT for disaster preparedness and mitigation [9]. Brooks [10] has described the National Center for Accessible Media's project entitled *Access to Emergency Alerts for People with Disabilities* with the goal to develop standards and guidelines for accessible alerts. Hakkinen and Sullivan [11] have discussed the application of accessible design to disaster warning and discuss research that is underway.

The Web provides one model for addressing the needs of those with disabilities through the development of guidelines and the addition of accessibility features into the underlying languages and protocols of the Web. Guidelines defined by the World Wide Web Consortium's Web Accessibility Initiative [12] for web content [13] and systems that present content [14], recognize the importance of providing alternative formats and mechanisms for receiving and interacting with information. The W3C efforts have been instrumental in the development of legislation by a growing number of countries that seeks to ensure that vulnerable populations are not excluded from the knowledge society. This same approach is vital for disaster preparedness and warning systems.

2. DESIGN ISSUES

Mobile devices, by design, generally incorporate three modalities of presentation, Audio, Visual, and Tactile. As a starting point for building accessible interfaces, this modality triplet is ideal, yet in practice, melding these elements together in a consistent and effective manner has received little attention by device manufacturers. With the advent of smart phones, some assistive technology vendors have taken the desktop PC model of the screen reader and have developed add-on software that allows those with visual impairments to interact non-visually with many mobile device features [15]. Nokia [16] has also released a series of Symbian-based devices that incorporate synthesized speech presentation of text messages and other information. But the addition of synthetic speech capabilities is only part of a solution, and issues with speech quality and intelligibility in mobile environments raise additional questions.

The concept of multimodal presentation, using a combination of auditory, tactile, and visual cues, to provide redundant channels of information is a promising approach for accessibility on mobile devices. Hakkinen and Sullivan [11] have described how lessons learned from accessible information design can be applied to public warning, and in particular the idea of parallel modalities, and within those modalities alternate renderings to meet specific needs. For example, speech and non-speech cues, textual, graphic, and animated images, and coded vibration all can contribute to the creation of effective information transfer. SMS delivered alerts can serve as an ideal application for examining the design requirements and the role to be played by government agencies, information standards (e.g., CAP) and the device manufacturers. The message generated must contain sufficient content and metadata to allow transformation and adaptation into an accessible (and understandable) format at the end user device. Lessons learned from Web-based information accessibility, and technical approaches such as found in the Synchronized Multimedia Integration Language (SMIL) [17] will be useful in this work. In particular, the content selection capabilities of SMIL are interesting in that a user's device profile can indicate a need for simplified language or animated symbols (for the learning or cognitively disabled), verbal descriptions of visual information such as maps for the visually disabled, or slowed presentation.

It needs to be further considered that bandwidth limitations and network congestions issues, particularly during a disaster, can severely impact the operational use of mobile alerts, and argues that redundant technologies (low tech sirens, TV, and Radio) also must have their accessibility addressed.

Efforts to create accessible preparedness materials are already underway, but their delivery on mobile devices is an area in need of further research. Complex information such as evacuation wayfinding poses significant challenges for those with visual impairments. Merritt, et al, [18] have described some of the challenges to the use of spatial audio as a component of accessible emergency wayfinding information presentation on mobile devices.

Empirical validation of design approaches for mobile device-based preparedness and warning is critical, but can be difficult to achieve when the experimental conditions can only approximate the actual conditions, and without the true sense of urgency, randomness of occurrence during the day and year, weather conditions, and the individual variations of location, well-being, and activity that define real life. Factoring in the need to evaluate system designs for usability by people with disabilities is vital, but is often perceived as difficult to achieve. Partnerships between disability organizations and those developing these mobile services are vital to ensure solutions are accessible to the intended populations.

3. CONCLUSION

People with disabilities and other members of vulnerable populations are at particular risk during disasters and other emergencies. Availability of accessible preparedness information and timely receipt of warnings and alerts will be essential to improving survival and well-being during these critical events. Mobile devices are seeing increasing use as a component of disaster preparedness and warning, yet these devices have had significant usability challenges for people with disabilities. It is vital that those designing and developing mobile-based systems incorporate accessibility features and evaluate usability with people who have disabilities. Historically the development of accessibility solutions has had benefit beyond the initial intended audience (e.g., curb cuts and closed captions). It is hoped, if not expected, that attention to mobile device accessibility will have benefits in improving the effectiveness of preparedness and warning systems for all.

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Explorations on Interactive Interfaces Using Cuteness

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The experience of interactive systems can be a rather complex set of events. The perceptions appeal to the user's senses including visual, auditory, tactile, olfactory, and gustatory. Taken from a human factors approach, the sensitivity of the senses can be measured very closely and units of measurement arise from the "just noticeable difference." These differences can be mapped to the physics behind the stimuli and computer controlled systems very accurately provide sensation to the user through various user interfaces. The human mind also plays an important role in making sense of the experience not only from a physiological standpoint, but from a psychological and cultural reference point. Many instinctual impulses can be elicited by interactive media for powerful, immersive experiences. The fight or flight response and sexual attraction have been used extensively in the top selling games, but we are looking beyond these toward the interfaces that aim to bring happiness and comfort. We look at a range of experiences involving the idea of "cuteness" and its related components. From a psychological standpoint, there are cues that are well known that are instilled in us at an instinctual level. An example is the features of babies that bring out a nurturing response. Measuring these reactions however is less discrete and is more qualitative in nature. From a cultural standpoint, the definition of how cute something is and what it drives the user to do in response is not yet fully explored. Toy and game manufacturers are continually striving to hit the "sweet spot" with the consumers in the various markets and sometimes produce a combination that has wide appeal and then due to a long lasting popularity it may also add or modify the cultural perception. Our studies look at what elements are perceived as cute and then understanding the reaction the user has to this. We are working towards a goal of providing the designers with a better understanding of today's interactive media users and developing ways to enhance the effectiveness of interactive media by utilizing the psychological and culturally developed symbols of cuteness. With these lessons learned, the next generation user interfaces can be built to take advantage of the "cuteness" factor and establish more meaningful relationships with the users and encouraging happiness and positive experiences.

Age Invaders: User Studies of Intergenerational Computer Entertainment

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Abstract. The design goal of the Age Invaders[1] system is to make a mixed reality interaction platform that can facilitate meaningful social interaction with players, from many backgrounds and demographics, at appropriate levels of physical exertion for their age. This paper discusses a multidisciplinary approach to analyzing the user experience and re-assessment of the context of use of the Age Invaders system. This paper tests the effectiveness of the system in promoting the intended design goals and the results show strong support for intergenerational interaction using digital technology. Additionally, the results of the study help to focus the refinements of the existing platform and development of further novel games and interactive applications for this mixed reality system, and provide insights into the user in complex mixed reality experiences.

Key words: Mixed reality entertainment, social computing, family entertainment, game play, user-centered design

1 Introduction

The research reported here aims to show the user acceptance of the Age Invaders (A-I) game system [4] by players of various ages. As a design goal, Age Invaders aims to provide engaging physical and virtual play for elderly and young together in a novel mixed reality entertainment system. Unlike standard computer systems, A-I requires whole body movements over a large play area rather than constraining the user to sit in front of the computer for long periods of time. Age Invaders provides family entertainment that is attractive to, and inclusive of, all family members including the elderly and young. The system encourages and promotes human interaction at the physical, mental and emotional level. A-I provides a means to re-connect family members in shared activities across locations, thus increasing cross-generational interaction. The research situation aimed to better understand the users of the A-I system and to take inventory of recurring user experience issues. The methods include questionnaires and other

[1] Videos and photos of the work can be accessed via the website http://ageinvaders.mixedrealitylab.org
Email address: contact@mixedrealitylab.org

qualitative data analysis borrowing from the grounded theory approach [2]. Our selection of users varied in many respects including age, physical ability, familiarity with computers and electronic games, and level of education in order to gain as much relevant input as possible.

2 System Description

The system consists of a game server which is connected to the Internet through a router, large floor display platform with embedded RFID tags, online virtual client for real time remote game play, Bluetooth display, controller and special slipper with embedded RFID reader for tracking of players. The system's inter-devices communication is completely wireless.

2.1 Age Invaders Game Play

The concept of the Age Invaders game is shown in Figure 1, two children are playing with two grandparents in this interactive physical space while up to two parents can join into the game via the internet as virtual players, thus increasing the intergenerational interaction. The grandchildren form a team and the grandparents form another. The parents' role is to balance the game between the two teams.

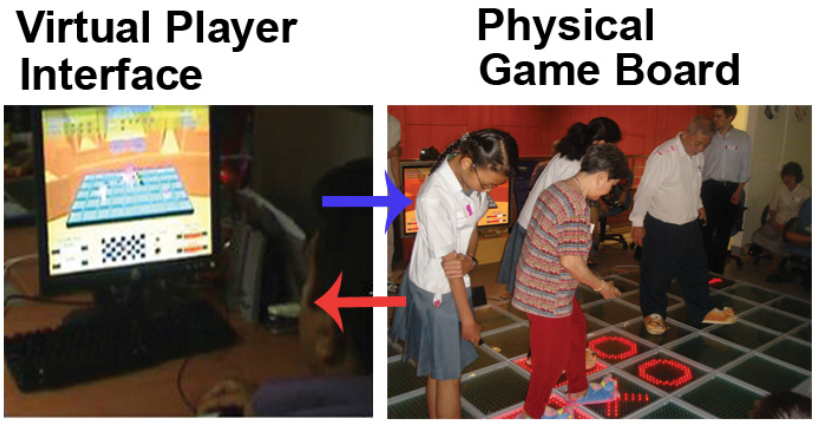

Fig. 1. Age Invaders: An inter-generational, social and physical game. Players are wearing cute RFID tracking slippers and holding Bluetooth controllers

Grandparents and grandchildren put on lanyard-style Bluetooth LED display for the purpose of displaying some game events. The players then wear the special slippers and pick up the Bluetooth controller.

Each game lasts for up to 2 minutes. The players gain points by picking up bonus items and avoiding laser beams. The player is out of the game when his or

her energy level drops to zero. The game ends prematurely if the energy level of both players of the same team became zero. Otherwise, at the end of 2 minutes, the team with the highest score wins.

During the game play, as the player presses a button on the handheld device, a laser beam image is displayed on the game board and heads towards the opponent. If the grandparent launches the laser, its speed is fast so that the grandchild has to react quickly. On the other hand, the grandparent has more time to react to the much slower laser beams launched by the grandchild. This balances the game difficulty between the ages.

In order to make the difficulty of the game strike a balance between the young and the elderly, Age Invaders imposes some challenges in an innovative way for the invader players (the young and more dextrous). The invader footprint is one of these challenges. In the game, the invaders have to physically follow the footprints and have to remain in the squares with footprints indicated with a pattern of lights which they see on the floor square. Each invader has two footprints from which to select as their next step. In any case that they are not stepping in the square that has their footprint indicated for a certain period of time, their energy is deducted. This period is determined by the invaders' footprint speed which can also be adjusted by the virtual players at any time. To be fair to these players, they are rewarded with one bonus health point by following the footprints correctly ten times in a row.

The parents as virtual players, can drag-and-drop barriers or energy on the virtual player interface which appears almost immediately on the physical game board rendered in patterns of lights. The physical players can pick up the bonus to gain extra energy and barriers will block laser beams. Parents can also adjust the game parameters as mentioned previously including: laser speed and the speed of the dance step patterns for the young players to follow. All the actions in the virtual environment are translated to the physical game board in real time. This provides a seamless game interaction between the real world players and the parents in the virtual world.

The game play challenges and aids are summarized below:

Young Player

- Must follow the dance steps as they appear
- Speed of laser beam is slower
- More difficult to collect power-ups unless intended for the player, due to need to constantly follow dance steps

Older Player

- Can move freely on the game board
- Speed of laser beam is faster
- Power-up hearts can be collected easily

Virtual Player

- Placing power ups and barriers
- Balancing the play experience by adjusting the step speed and laser speed

3 Method

3.1 Design

Games play sessions were conducted in a controlled laboratory setting. Users answered questionnaires before and after game play sessions to gather levels of enjoyment, contributing and detracting factors on the game play, and social aspects of the experience.

Additionally, case studies of other sources of data were reviewed using a grounded theory approach borrowing from the methods offered by Glaser [1]. We conducted focus group discussions with users immediately following a two hour session of game play and began the note-taking process.

As more of the themes emerged, some categories of issues affecting user experience provided a framework to organize the concepts. Subsequent review of data gathered from open ended questions from the same user group helped to confirm these categories and in some cases provided candid feedback that respondents in a group situation chose to withhold. For the older adults, we also conducted a follow up focus group session 5 weeks after the first focus group session. In this later focus group, we probed the issues of the gameplay experience to understand the lasting impressions and the issues that were most memorable for positive and negative aspects of the game play. The design team then reviewed the categorized data and wrote summaries of the observations. The researchers were also encouraged to reflect on the observations and user statements of players and spectators engaged in the system during the conference exhibitions and to compare against the more structured game play sessions. With the categories defined and researcher notes gathered, the process of producing the theory of the user experience issues in the form of linear and coherent statements was undertaken.

3.2 Data Sources

Among the data sources reviewed were video recordings from platform demonstrations at conferences, structured game play observation of 49 players in a structured format, questionnaires involving closed and open-ended questions, 3 focus group discussions involving the 49 players immediately after the gameplay and 7 of the older adults 5 weeks after the game play, and 4 semi-structured interviews with the design team and gameplay facilitators.

4 Results

4.1 Profile of Users

The data from the users came from observations made at various conferences and exhibitions including CHI 2006 (Canada), Interactive Tokyo 2006 (Japan), Greenfield 2006 (Singapore), Singapore Science Center i-Future 2007 (Singapore), NUS Arts Festival 2007 (Singapore).

In the first focused gameplay sessions, there were 2 groups from the Ngee Ann Polytechnic in Singapore, taking part in a study module about electronic games were invited. These initial sessions involved a total of 37 total participants. The average age of the participants was 19 years old. The gender of these participants was 24 males and 13 females.

An additional gameplay session was organized involving the intended age disparity of the players. There were 10 students from the Hougang Primary School, with average age of 11.7 years. There were 7 females and 3 males. The opponents were the older players who were invited from a community center in the Jalan Basar area of Singapore. The ages of these players ranged from 58 to 80, and an average age of 68.7 years made up of 7 females and 3 males. It is worthy of note that a majority of the older adults self reported that they are illiterate. The older players spoke Hokkien or Cantonese, yet understood Mandarin that was spoken by the children. The children spoke in the Chinese dialects of the older players, but also Malay and English amongst themselves.

4.2 Teen Player Study

The first formal studies were aimed at showing the acceptance and enjoyment of the Age Invaders game by younger players that have familiarity with contemporary electronic gaming. Prior to game play, the respondents were asked to rate themselves in experience level with electronic games choosing between the categories Newbie, Casual User, Moderate User, and Hardcore User. The results showed that 78% of the players were casual to hardcore users. All of the users reported that they do play some kind of electronic games.

After the game play sessions, the users answered additional questions pertaining to the game experience. Most importantly, the respondents were asked to rate their enjoyment level with the game. Overwhelmingly, the respondents enjoyed the game play as shown in and would recommend it to be used for encouraging social interaction within families. The users were asked to indicate their level of agreement with the statement, "I enjoyed the gamplay experience." As shown in Figure 2a all respondents chose "Agree or Strongly Agree."

Players were also asked to rate their agreement with the statement, "I would recommend this game to be used to encourage social interaction within a family." The strength of their positive sentiment is shown in Figure 2c. Only one of the players disagreed with the statement.

The players were asked to indicate their level of agreement with the statement, "The skills required by the game were well matched to my skills and experience." The responses showed that 84% Strongly Agree to Somewhat Agree that the game play experience was well matched to their skill level and experiences. The responses are represented in Figure 2d.

The users showed preference to the four-player configuration compared to the two-player format according to their responses. The responses showed again that 84 % Strongly Agree to Somewhat Agree that the four-player game was more enjoyable. This is shown in Figure 2b. In the focus group discussions, the

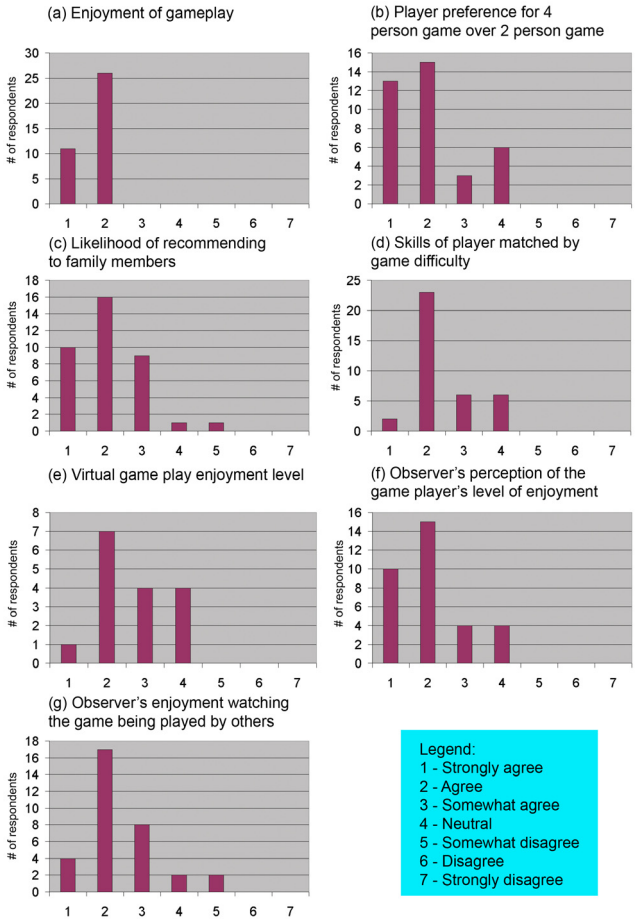

Fig. 2. Responses to questions based on a Likert scale. 1-Strongly Agree to 7-Strongly Disagree.

users explained that the four-player games were more exciting and having a team member to engage in cooperative competition

Most players also had a chance to take part in the game as a player in the Virtual role. The level of enjoyment was less, but showed positive sentiment towards the virtual play. In this case, the players were asked to indicate their agreement with the statement, "Playing via the virtual player was fun." The results of the satisfaction levels are shown in Figure 2e.

In order to determine what was enjoyable vs. not enjoyable, we discussed the virtual game play in the focus group discussions and some themes emerged and were reinforced. These themes are discussed in the Emergent Themes section.

Because the game system may have spectators, we also asked questions about the experience as an observer. Respondents were asked to indicate their agree-

ment with the statement,"The game seemed fun to play from the observer's point of view" This data is represented in Figure 2f. Additionally, the spectators agree that watching the game is enjoyable as shown in Figure 2g.

4.3 Young and Elderly Player Study

With a general understanding that the game is enjoyable to play from the younger audience point of view, the more critical study came when conducting the play sessions for the older generation playing with a younger generation as shown in Figure 3.

Fig. 3. Age Invaders players taking part in a gameplay session.

The questionnaires were made in simpler language and with fewer questions in general to avoid overloading their first experience with electronic games. An important assumption to test first was our thought that the older players were not familiar with electronic games. Responses showed that 80 % of the children reported playing computer games, while the adults all reported never having played electronic games.

In order to determine their habits with their families, all players were asked if they play any games non-electronic or otherwise with their families. 60 % of the young reported that they play some type of game, while only 30 % of the older players reported playing games with their families. Those that do play games with their families reported similar types of games regardless of age. The older generation reported playing chess and cards with their families, while the children reported cards and board games.

In order to "break the ice" and to get the two generations of players to interact and converse, players were organized into 5 teams of 4 players each. Each team was made up of 2 young players and 2 older players. These players made name tags for each other, introduced their teams and the children were designated as the scribes of the teams and would help the older players to fill out the questionnaires in English. Each team was also designated a game studies

facilitator from our lab who helped to ensure that the questionnaires were filled out appropriately and honestly. The game sessions were conducted similarly to the previous studies mentioned earlier. Again, overwhelmingly the players enjoyed the game experience with all respondents reporting a positive sentiment with nearly all respondents showing positive experience and only one reporting a neutral experience.

The user's were also asked, "Can you imagine your family enjoying the game?" The overwhelming response showed a high motivation to play the game with their families. All of the young people reported that the game would be appropriate for family play, while 80 % of the older players answered positively. In order to understand the differences in the age, we discussed this in the focus group and found that the respondent who did not imagine playing the game with her family did not previously consider extended family members when answering the question. In the focus group she mentioned that she discussed the game with her niece and felt that she would enjoy playing the game in a family setting.

4.4 Focus Group Session with Older Players

Five weeks after we conducted the initial user study for the elderly and young, we went back to the senior center to conduct a follow up focus group session with 7 of the elderly players. Our aim was to investigate the longer lasting impact of the Age Invaders game. When prompted the most memorable thing about the game, all of them mentioned the launching of lasers, avoiding lasers and chasing after the hearts on the game board. "This is a fresh idea and it was my first time playing" quoted by a few of the elderly. They are all excited about this new entertainment platform. Two elderly have shown some interest to understand what technology is behind the platform. Many related Age Invaders to the popular arcade game, Dance Dance Revolution. In almost identical questions, there were two older adults that stated, "I suppose there are computers controlling the shoes, controller and floor display, but how?" More detailed technical explanations were given, and we then asked if they have an increased interest in trying out other electronic/computer based games as a result of their experience with A-I. To this question, all of them gave a negative answer. Some of the reasons given were the fact that they are illiterate and they have no prior experience with operating computers. It seems as though the older adult players see the game system as being so different from traditional computer systems that the relative level of comfort with traditional computer platforms is unchanged after playing the A-I game.

Among other issues, a consensus was made amongst the elderly that the sound was too soft in the game and they strongly suggested that the new version of the game incorporate louder sounds and music to accompany the play session in addition to the sound effects already present. More specifically, most of the players expressed a desire for a sound event indicating the game outcome and a larger screen for displaying the game score. "We do not understand words, so just display the numbers like those in a basketball tournament", was suggested by one of the elderly.

When asked what skills were involved in playing the game and about the difficulty level, all agreed that the game was easy to learn, and that the game speed was fine, but a few mentioned that the pace could be a little slower in order to play for longer amounts of time. However, they emphasized that the game speed cannot be too slow otherwise it would become boring. The current game pace is exciting for them. This was well stated by one of the players, "The game gives me good exercise. When you see heart, you have to run to collect it. If a laser is approaching, you have to avoid it quickly. The game is very engaging and can we play it again?" This supports the design goal of providing a game that challenges the elderly in terms of visual-motor coordination and physical activity level.

When asked about how much fun was the game you played, they all gave the maximum rating. "Thinking about it now, we can't wait to play again!" said one of them. It is obvious that the elderly players have enjoyed the game and have high motivation to play the game again. Of particular interest is the fact that the users don't see a strong connection between this system and traditional electronic gaming and computing in general. This high motivation level is valuable in and of itself as confirmation that older adults can be engaged in new technologies and have high enjoyment levels.

4.5 Emergent Themes

As the data coding process continued, the themes developed into to two main categories. These categories were related to the Physical Player and Virtual Player. Issues that were reported by user statements and supported by additional observation are now presented.

Physical Player Issues Regarding the physical game space and player activities, there were Four issues that emerged: Strategies were developed, Stepping action was enjoyable, The smart slipper should be user friendly, and the handheld device and personal display should have more features.

Strategies Developed

Through demos, exhibitions, and user studies, the researchers observed many interesting strategies employed by the defender team. The defender team member, knowing that the invader only has two boxes to stand in, blocks one of the spaces. This prevents the invader from moving in any direction. The defender can then trigger the laser beam and the invader loses a heath level. The aspect that makes an activity a game is the need to make decisions [3] [6]. Defenders derive satisfaction from the game play as they claim direct responsibility for winning the game due to their strategies in the game. On the other hand, the invaders have less freedom of movement as they have to constantly follow the flashing patterns on the floor. Failure to do so means losing a health level.

Stepping Action is Enjoyable

The invaders often enjoy following the dance step-like patterns on the game board despite being limited to two squares at any one time. This could be affected

by the presence of audience members who are spectators to the performance. In traditional computer games, the audience passively watches the player exploring the game. However the performance play elements introduced by the dance step-like movements give the invaders an expressive visibility which encourages acting by the player and more audience support. We observed that the audience is continually shouting to the invaders as to where he or she should step next. This is especially useful when the patterns are behind the invaders and the audiences give a timely cue to power up. Following the step patterns requires some level of physical exertion that brings the invaders to a highly energetic game play. The audience's support and feedback also gives invaders a sense of responsibility for the performance that they put up. Some invaders are overwhelmed by the tasks of following the step patterns, avoiding the approaching laser beams and trying to launch one at the same time.

It turns out that the footprint makes the game more interesting and challenging to the young and easier for the elderly. The young players have to constantly search in all directions for the footprint patterns on the floor and at the same time try to launch laser beams towards the opponents and avoid the opponents' laser beams. Furthermore, the young players' laser beams are, by default, significantly slower than their older counterpart. This has encouraged great team work between the elderly and young player as the older team player always alerts the young player for approaching laser beams.

The Smart Slipper Should Be Easy To Use

The usability of the smart slippers presented a particular challenge to the older players most likely due to their reduced mobility and dexterity. All of the adult players agreed that easily adjustable slippers are needed. One generally accepted feature change idea by the older players was to use an adjustable velcro strap to adjust tightness of fit. Otherwise, the use of the slipper was enjoyable and its cute styling was well received.

Performance Aspect

This theme came up in many aspects which have been mentioned in most other topics. This may be a parallel to human nature as seen in professional sports. The "happening" itself is a large portion of the experience. The players often responded to the cheers and shouts from the audience and reacted to suggestions and hints. The audience helped to raise the awareness of which team was winning and losing and also seemed to raise the excitement level of the players. Some of the younger players were shy at the beginning of the game, however, they would loosen up quickly and the shouts from the audience were encouraging them to play freely. Some of the younger players adopted a special finesse to their play which was accompanied by their playing off the audience and making exaggerated gestures when facing challenges and scoring points.

Virtual Player Issues The players were briefed about the design goal of having a parent fill the virtual player role. In the proposed user scenario, grandparents and children would play in the physical space and the parent would join in as a virtual player while away from the home. Users of all roles were asked to

describe their impression of the family interaction scenario and most imagined that their family would enjoy this interaction. The players that had also played in the physical space also had a chance to play in the virtual player role. The most prevalent issues that arose regarding the virtual player were as follows:

Virtual Player Role Is Currently Not As Much Fun As The Physical

Although the players enjoyed the virtual role, the sense of connectedness and ability to take part in the gameplay was not as enjoyable.

More Features Desired For The Virtual Player Experience

Most of the suggestions offered included a desire for more and varied power-ups and obstacles as a way to expand the sense of presence in the game play.

Balancing Gameplay For Other Players Was An Interesting Concept

The virtual players took on a sense of balancing the game play between invaders and defenders, not focused solely on helping just one team. Being in the constantly switching team position, one instant helping the invaders, but in the next moment helping defenders, the virtual players often did not identify themselves with either the winning or losing team but agreed that the interaction was rewarding as an activity of facilitator of fun. In this sense the virtual player has to follow the game progress closely and provide assistance where it best contributes to the overall game experience for all players. Suggestions for improvement include having a virtual helper for each team in the competition scenario. During the game play, the physical players can communicate in the physical space by eye contacts, body gestures, speech and laughter which introduce a high level of engaging and immersive game play. However when translated to the virtual player's interface only the coordinates of the physical players are represented and the emotional connection is not as firmly established. In the future developments, web cam and voice over IP could be introduced to facilitate better coordination and interaction amongst all players and within teams.

5 CONCLUSION

Our play based user studies support the claim that the Age Invaders system is engaging for the physical and virtual players of all ages. We have identified key areas that contribute and detract from the experience.

The older players have shown a high motivation to play the game again immediately after the game play and even after considerable time has past since they have played the game. Players have given feedback that physical movements and skills needed in the game, such as collecting hearts, avoiding lasers and launching lasers, and the aspect of performance made for very exciting and enjoyable play. It may be that the introduction into the computing world using this game system may help to reduce the fear of technology and therefore reduce the social barrier between the generations. This may be more fully explored with future user studies over a longer period of time and with more game configurations for the platform.

Playtesting of game iterations is especially important for the elderly because their familiarity with gaming technology is limited. Mere interviews and surveys

attempting to gather feedback from the elderly can not gather useful results. These players confirmed that it is more appropriate to offer a prototype to evaluate by experience.

The familiarity with electronic games and computers in general is an important factor in the player experience. Those most familiar with contemporary computer games can enjoy more simplified game graphics such as in the Age Invaders prototype, but the challenges need to be presented at appropriate levels to hold the player interest and motivation.

Unlike conventional computer games, Age Invaders encourages large physical movements over a wide area. The user study results support our claim that the Age Invaders game is a form of exercise for the elderly. Participation in such an activity helps the elderly feel healthier and encourages movements that may promote health [5]. In the future, user studies will be conducted to investigate to what degree the elderly visual-motor reaction time improves through playing the A-I game on a regular basis.

Social interaction has been identified as the key factor that attracts the elderly and young to play the game harmoniously. 84% of the players enjoyed the experience of playing the four-player over the two-player game. The elderly and young gave feedback that the game should be played with many spectators.

Another strong point indicated was the performance aspect of playing the game. We will explore this more closely to determine how the audience affects the game experience and search for limits and optimum scenarios of interaction.

It is our hope that this project will encourage more future works aimed at fusing art and digital games to fulfill the scientific objective of improving the welfare of older people and the entire family.

6 Special Thanks

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