Adrian David Cheok

Art and Technology of Entertainment Computing and Communication

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Advances in Interactive New Media for Entertainment Computing

Foreword by Ryohei Nakatsu

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Dr. Adrian David Cheok
National University of Singapore
Mixed Reality Lab
7 Engineering Drive 1
117574 Singapore
Singapore
E-mail: adriancheok@mixedrealitylab.org
Twitter: @adriancheok

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To my grandfather, and hero, Emmanuel Pantahos on his 85th birthday. To my mother. To Midori, and our sweet daughter Kotoko.

Foreword

New Communications and the Direction Our Society Moves Toward

Various kinds of new media that appeared in the last ten years have been quickly changing the way we communicate each other. These new media include mobile phones, Internet, game machines, etc.

For example, mobile phones changed our communications way as they can connect us anywhere, anytime. Suppose that you are on a plane that has just landed and arrived at a terminal. What do passengers do first? More than half of them take out their mobile phones, turn them on. Some start checking e-mail and some others start calling their family members only to say “I have just arrived”. Suppose that you are a business person attending a business meeting. Probably the first thing most of the attendees of the meeting would do is take their PCs out of their bag, turn them on, and start checking something. Are they checking documents for the meeting? No. What most of them are doing is checking their mail box, answering some of the business/private messages. Also look at the life style of your children. You recognize that they spend a large part of their time at home playing games instead of having a talk with other family members.

The most impressive fact in these phenomena is that this is happening all over the world, both in the Western and in the Asian countries. We have been discussing how we could realize globalization overcoming different nations and different cultures. Already we live in a world of globalization.

Another fact is that these phenomena are happening in various instances of our everyday life. For this we should understand that communication is a most typical human behavior. Reflecting your everyday life, you would understand that most of your behavior could be interpreted as communication. For example, most of the children’s behavior at school is communication; listening to the lectures of teachers, having a discussion in their class, etc. are typical communication behaviors. Also most of the business at an office is communication. You would talk/discuss with your colleagues and the boss. Also you would attend a meeting. Or you would read/write e-mails. Even when you prepare some document, this could be interpreted as communication with your PC. After coming back to your house, you would enjoy watching movies/drama on TV or reading a book. Watching movies and reading novels are also one form of communication as you are receiving messages sent form the writer of the book or the director of the movie.

These things mean that the new media are changing almost all aspects of our life. Therefore, we should be careful about the direction these new media would change our way of communication and lead our society. At this point, I want to suggest that there are two significant changes in the way we communicate.

The first is that the non-logical aspect of information plays an important role in our recent communications. When we refer to communication, this used to mean conveying logical information and sharing it among a sender and a receiver. What is happening nowadays, especially among communicating youth, is that they are sending non-logical information, in other words, emotional or Kansei information, to each other. Mainly what they are talking is not business, but about the movie they watched or about the food they ate. This means that they are exchanging their experiences, and as a result they want to share the same emotion/feeling. This is something more than sending and sharing information. In this sense, the basic concept of communication has been changing.

At the same time, I want to emphasize that "Asianization" of communication is going on among Westerners. Please pay attention that the above emotional communication, or Kansei communication, is the basic form of human communication. But through thousands of years of human history in the Western cultures, the emphasis has been on the logical thinking as the basis of human intelligence and on trying to extract logical communications from emotional communications, thus trying to keep this emotional aspect only to the private life. On the other hand, in the Asian countries people did not succeed in separating logical and non-logical aspects of communications. Especially Japanese have been executed because they had not been able to separate Tatemae (formal opinion) and Honne (private opinion). However, we should notice that the emerging of new media again took back Western people to the old style of communications, i.e., emotional communications.

Is this a new trend? The way we communicate is coming back to its original form both in the Western and Asian countries. In this case, as communications are a basic form of human relations, this phenomena would give strong effects on the Western way of thinking, and finally to the Western cultures. Or is this only a transitional phenomenon as these media are totally new to us, and gradually the Western people would invent how to use these new media in the traditional logical communications form?

Still it is too early to judge this. What we should learn now is various aspects of this Kansei communication, and we should try finding a new way of communications that would give us a new way of life. Therefore, it is essential for the researchers in this field of new media to study the various kinds of new communications which our technology could realize and thus give people a chance to understand by themselves the new communication ways they could have in the future, and so that people could choose the direction they would go. We need young talented scientists who would devote themselves in such research.

The author of this book, Adrian Cheok, is one of the most brilliant and talented scientists who are doing such research. He has been working in the area of virtual and mixed realities for many years. His main interest has been in developing new ways of communications using technologies. By connecting the real and virtual worlds, he has been trying to develop various kinds of new demonstrations which would reveal us a new way of being connected to each other, overcoming the time and space gap. His interest did not only stay with human communications. He tried to realize human–animal communications and even human–plant communications. By reading chapters of this book, the readers will understand what I mean by “new communications” and will know the direction our society is about to move towards.

Kyoto *Ryohei Nakatsu*

Preface

Just like previous seismic shifts in civilization, the net age has produced a massive change in civilization. The main effect of this shift has been the instant, global, and constant communication, and so in some way this has been a revolutionary change of human communication. What this has meant is that the net generation grow up with new forms of play and communication from previous youth. Their entertainment is immersive, fantastic, and can be played together with thousands or millions of people around the world. Their communication is instant, from many multiple sources simultaneously, constant, and global. In some way there has been an end of solitude (which may also have negative consequences). Now, when the net generation goes to school, they find it totally different, and more and more irrelevant to their daily lives. They are used to constant, immersive, simultaneous multiple source communication. Sitting in a traditional classroom, and being told not to use their mobile phones or send messages must be totally boring and frustrating to them. Having one source of information from the teacher must seem so slow. Students may feel they wish they could press a fast-forward button to the teacher.

Not only the young net generation but also all of society has radically changed. Grandparents are playing games on Nintendo Wii or DS, and parents are using Twitter. What this means is that in general we must understand the new entertainment and the new communication in order to enrich learning and education that is relevant, and also to allow work, family life, and elderly care become more relevant and enriching.

I hope this book will be informative and inspirational to students and the next generation of researchers who will change the world and society for the better through new modes of entertainment and communication. I hope this book will also be useful to academics, researchers, engineers, game designers, interaction designers, venture capitalists, etc. With quantum step innovation and inventions, we can make a better society for children, families, and elderly.

Singapore and Tokyo *Adrian David Cheok*

Acknowledgments

This book represents work done together with my students and research staff in the Mixed Reality Lab at the National University of Singapore. Over the years, I have had great pleasure working with several very hard working, talented and creative students and researchers in Singapore. The research described in this book very often required many high pressured late night, weekend, and all night works to meet deadlines such as conference paper submissions, or preparing for international demonstrations, and I really appreciate such great dedication and hard work. Not all students can be so dedicated, and many give up, so I am extremely happy to see those students and researchers who passionately believe we should aim for quantum step innovations and inventions, rather then do incremental research. This way we can help change society for the better, which should be the ultimate aim of researchers. I am deeply grateful for the great work of each student and researcher who helped carry out the research, and also for the help writing the chapters. Each student and researcher, co-author from my lab or otherwise contributor to the project, is listed in Table 0.1.

For this book, I invited some of my closest external collaborators and colleagues to write two of the chapters. Chapter 10 was written by Professor Masa Inakage, and Chap. 11 was written by Professor Michael Haller, with their students and colleagues. Their research represent some of the most interesting and innovative work in entertainment computing, so it is a great honor that they could contribute a chapter to this book.

Without the support of the university and sponsors, the research work described in this book would not have been possible to carry out. Thus, I would like to thank my National University of Singapore (NUS) colleagues, particularly Professor Yeo Swee Ping, former Head of the Department of Electrical and Computer Engineering, who really helped and supported my work in the early days, and Professor Tan Chor Chuan, who is now President, and has supported my work over the years. Thanks go also to the DSTA (Defense Science and Technology Agency) in Singapore for supporting and being major funders of my work throughout the years, from the early years onwards.

Professor Hiroshi Ishii of MIT Media Lab has been a great inspiration and mentor to me for my career, and his harsh but excellent advice and critique made me stay

Table 0.1 List of co-authors

Author name	Contributed chapters
Dilrukshi Abeyrathne	Chap. 9
Yongsoon Choi	Chap. 7
	Chap. 9
Makoto Danjo	Chap. 9
Chamari Priyange Edirisinghe	Chap. 9
Owen Noel Newton Fernando	Chap. 2
	Chap. 3
	Chap. 4
	Chap. 8
	Chap. 9
Kasun Karunanayaka	Chap. 9
Zhu Kening	Chap. 8
	Chap. 9
Eng Tat Khoo	Chap. 6
	Chap. 8
Nancy Lan-Lan Ma	Chap. 9
Yukihiro Morisawa	Chap. 8
	Chap. 9
Roshan Lalintha Peiris	Chap. 4
	Chap. 7
	Chap. 9
Nimesha Ranasinghe	Chap. 8
	Chap. 9
Hooman Aghaebrahimi Samani	Chap. 4
Assoc. Prof. Annett Schirmer	Chap. 7
Roger Thomas Tan	Chap. 2
	Chap. 4
James Keng Soon Teh	Chap. 5
	Chap. 7
	Chap. 9
Ranjith Vijayakumar	Chap. 7
Liu Wei	Chap. 2
	Chap. 3
Janaka Prasad Wijesena	Chap. 4
	Chap. 8

on track to always do something new, to be a true engineer and inventor, and to aim for quantum step research.

I would like to thank Professor Masahiko Inami, Professor Yung C. Liang, and Mr. Ivan Boo for their trust, kindness, advice, and support, especially during the tough times.

Contents

Chapter 1
Introduction

It is the speed of electric involvement that creates the integral whole of both private and public awareness. We live today in the Age of Information and of Communication because electric media instantly and constantly create a total field of interacting events in which all men participate.
Marshall McLuhan, Understanding Media, 1964

Over the past few decades there has been a revolution in computing and communication. Machines that once occupied whole rooms have moved to the desktop, the lap and palm, and into clothing itself. Stand-alone systems are now networked with each other and a wide range of different devices across vast distances. One of the consequences of this revolution is an explosion in Interactive Media technologies. Interactive Media is one of the main developments that emerged as a product of the technological, intellectual, and cultural innovations of the late twentieth century.

Interactive Media means much more than the convergence of telecommunications, traditional media, and computing. Using Marshall McLuhan's definition of media as an "extension of man", new media includes all the various forms in which we as humans can extend our senses and brains into the world. It includes new technologies that allow us to facilitate this new communication, and to create natural and humanistic ways of interfacing with machines, as well as other people remotely over large distances using the full range of human gestures such as touch, sight, sound, and even smell. Thus, new media includes new ways of communication between people, between cultures and races, between humans and machines, and between machines and machines. The vision of new media is that it will bring about radical developments in every aspect of human lives in the form of new kinds of symbioses between humans and computers, new ways of communication between people, and new forms of social organization and interaction. It will drive a revolution in finance, communications, manufacturing, business, government administration, societal infrastructure, entertainment, training and education.

In order for businesses and countries to flourish commercially and culturally in the new millennium, it is necessary for them to understand and foster growth of Interactive Media technologies, and open-minded creative experimentations.

A.D. Cheok, *Art and Technology of Entertainment Computing and Communication*,
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In this book, we will look at a blue sky research perspective on the field of interactive media for entertainment computing. Entertainment as an end-product is amusing; as a tool it is powerful. The power of entertainment stretches far beyond venues for amusement [21]. Entertainment is a key driver for development of technology. It is able to excite, motivate, satiate, communicate and inspire. With powerful functionality of entertainment, it is being applied to all aspects of life from learning, training, designing, communicating and collaborating everywhere. Therefore, there has been a lot of recent research put in the entertainment industry and it has grown dramatically as a topic of research interest. The book explores the future of entertainment technologies and aims to describe quantum step research. It hopes to inform and inspire readers to create their own radical inventions and innovations which are not incremental, but breakthrough ideas and non-obvious solutions. One of the main explorations in this book will be to examine how new forms of computer interaction can lead to radical new forms of technology and art for entertainment computing.

To make breakthrough ideas in entertainment computing we can draw upon the methods developed at places such as Xerox PARC, Disney Imagineering, and the MIT Media Lab, and by visionary individuals in computer interaction such as Douglas Engelbart, Alan Kay, Jaron Lanier, and Hiroshi Ishii (to name just a few).

The seminal works done by these pioneers were all achieved with small teams of "Imagineers" of multi-disciplinary teams of computer scientists, electrical engineers and product designers together with graphic designers, artists, and cognitive psychologists. The work can be termed "Imagineering", or the imaginative application of engineering sciences. Imagineering involves three main strands of work:

- Imaginative envisioning – the projections and viewpoints of artists and designers;
- Future-casting – extrapolation of recent and present technological developments, making imaginative but credible ("do-able") scenarios, and simulating the future;
- Creative engineering – new product design, prototyping, and demonstration work of engineers, computer scientists, and designers.

In this book, we will focus on two major strands of new interaction design and their effects on entertainment technology and art. These are the related research areas of embodied media and mixed reality. It is therefore useful to outline and introduce these research topics below.

1.1 Introduction to Embodied Media

Ubiquitous human media foresees that the future of human–computer interaction will lie in an interface to computing that appears throughout our physical space and time. Thus, humans as physical beings now actually become situated inside the computational world. Extending HCI through concepts of phenomenology and defining the main theoretical roots of both tangible and social computing, Paul Dourish defined a new field of embodied media [8].

Embodied media is a next generation interactive media and computing paradigm that involves the elements of ubiquitous computing, perceptual user interfaces, tangible interfaces and interaction, as well as computer supported collaborative work and social computing. The thesis of embodied media is that all these interactive elements have a common foundation, and that this foundation is the notion of "embodiment". By embodiment, we mean the way that physical and social phenomena unfold in real time and real space as a part of the world in which we are situated, right alongside and around us. Thus, it brings the opportunity of placing computation and interaction through and with the environment, as well as incorporating the sociological organization of interactive behavior.

Important research paradigms that incorporate embodied media can be said to be Weiser's ubiquitous computing, Ishii's tangible bits or "things that think", and Suchman's sociological reasoning to problems of interaction. This sociological reasoning recognizes that the systems we use are embedded in systems of social meaning, fluid and negotiated between us and the other people around us. By incorporating understandings of how social practice emerges, we can build systems that fit more easily into the ways in which we work.

Weiser's [24] philosophy of ubiquitous computing derived from the observations that the most successful technologies are those which recede into the background, and become an unnoticed feature of the world we live in, and secondly, from the observation that computing power is becoming so small and so cheap that it is now really possible to embed computing devices in almost every object and every facet of our physical environment. Weiser saw from these two observations that this would allow computation to be embedded and recede into the environment, allowing new possibilities and completely new uses of computing. Essentially, the environment becomes a distributed computer and responds to people's needs and actions in a contextual manner.

Ishii's [11] vision of tangible bits or "things that think" has its origins in Weiser's work in terms of embedding computing in the environment, but has led to a distinct development because Ishii observed that we operate in two different worlds. These two worlds are the computational world and the world of physical reality. Ishii termed these two worlds the world of "bits" and the world of "atoms". Through tangible bits, Ishii has set out to bring these two worlds together, and allow the computational world to engage and employ our physical and tactile skills which we are intimately familiar with.

It can be seen that ubiquitous computing deals with computing in the environment and with activities that take place in the context of the environment. Also tangible interaction deals with using the physical world and objects and physical space manipulation to interact with the digital world. They are related by sharing the viewpoint that interaction with computers should exploit our natural familiarity with the physical environment and physical objects, and to tie the interaction with computers with physical activities in such a manner that the computer is embedded in the activity. In this way, the environment and physical objects become the interface.

Another research paradigm which is incorporated into the idea of embodied media is social computing, or the study of context in which interaction with computation occurs. The important work of Suchman [22] on this topic draws on ethnomethodology to analyze interaction and social conduct. In ethnomethodology, social conduct is an improvised affair which is real-time and nonlinear. This perspective argues that the context in which interaction takes place is what allows people to find it meaningful. Experimental investigations have found that people's interaction with technology does not follow formal theoretical abstracts but is improvised in real-time.

These research visions have a central strand that deals with the role of context in interaction. The role of context is seen in the spatial and temporal context found in ubiquitous computing, the physical context found in tangible computing, and the social, cultural, organizational, and interactive context found in social computing. Thus, all are mutually dependent on the concept of embodiment, or a presence and interaction in the world in terms of real-time and real-space. Hence, they define the concept of embodied media.

For example, ubiquitous and tangible computing is the idea of the computer being embedded in our environment, in objects, and in the background. Thus the interaction is embodied in the physical environment, rather than on abstract representations on a computer system. Similarly, social computing places the real-time and real-space activities of humans as social beings, or embodied actions, at primary importance. Embodied media ties all these ideas together, as a single research vision. Furthermore, embodied media foresees that the future of human–computer interaction will lie in an interface to computing that appears throughout our physical space and time. Thus, humans as physical beings now actually become situated inside the digital media.

Through embodied media, new computer and cybernetic systems will improve our lives and create new and seemingly amazing possibilities in human society. We can foresee a future where, instead of humans needing to adapt themselves to computers and electronic systems, computers interact with people in a totally natural and human-like manner to make life easier.

Embodied computing in the context of entertainment and communication systems can use mixed reality to allow the concepts of ubiquitous computing, tangible interaction, and social computing to be concretely implemented. Thus, the concepts of mixed reality are briefly introduced below.

1.2 Introduction to Mixed Reality

Mixed reality [2] (the fusion of augmented and virtual reality) is a technology that allows the digital world to be extended into the user's physical world. Unlike virtual reality in which the user is immersed in an artificial world, mixed reality operates in the user's real world. This is made possible through the use of head-mounted displays where the user's real-world view can be overlaid with 3D computer graphics, text, video, audio and speech.

Mixed reality can be used to develop an almost magical environment where the virtual world, such as 3D computer graphics images and animations, is merged with the real world as seamlessly as possible in real time. For example, architects could work on a realistic virtual 3D model on their desk, and then enter the model together to explore the inside of the virtual buildings; surgeons could "see" the inside of a patients body before operating; children could see animals from exotic lands, and play with them in their real physical space; people could play games with each other together with virtual characters or creatures that appear in their real environment. In the military, there are vast applications of mixed reality in battlefield visualization, simulation, and training, soldier information systems, maintenance, and security.

Hence mixed reality can become a highly important component of future computing systems. It will allow humans to interact with each other in ways that now can only be imagined, and will allow humans to interact with computers in a way that goes beyond the desktop computers we have now.

Mixed reality allows tangible interaction with 3D virtual objects. For example, by moving a physical object, or marker, one can move and interact with virtual objects as if they were real objects in our physical world. Thus, a form of tangible interaction between the physical and digital world is achieved. Later in this book, a tutorial-like chapter on developing simple marker based mixed reality systems will be introduced.

Entertainment art and technology developments using embodied media and mixed reality opens up exciting new opportunities in the areas of computer graphics and human–computer interface development. We can expect applications in a great variety of areas such as education, architecture, military, medicine, training, sports, computer games, tourism, video conferencing, entertainment, and human welfare.

Using our technology, the following entertainment and communication scenarios are possible:

Holo-phone technology	While making a telephone call, the person who you are speaking to transfigures in front of you like the way Princess Lea appeared in holographic form in Star Wars.
3D books	For example, on Ancient Greece, where you can read a real book, and then see 3D figures of Greek mythical figures on the actual pages, moving and gesturing. Then you can "fly" into the book and experience what the Ancient world felt like.
Sports training	For example, watching a famous ice skater appear on actual ice, and to be able to "freeze" the skater in her actions so that you can look at key aspects in 3D.
Training simulators	The use of mixed reality greatly enhances training realism in training-simulators. In particular, the technology can be implemented on military combat-platforms (tanks, helicopters, armored fighting vehicles, etc.) to provide combat simulation when the platforms are operating in real-terrain environment. Computer-generated objects (obstacles and enemy combatants) are superimposed onto the real terrain to provide simulated combat.

Computer games	For example, where 3D figures move around in your actual physical world, just like the holographic chess game in Star Wars. Furthermore, imagine computer games where your friends in 3D form appear in the game, for example, a football game together.
Live virtual tours	For example, imagine walking on a guided tour of the real New York Metropolitan Museum of Art in the privacy of your home without having to go to New York. You can see it floor by floor and item by item just like on a real visit.
Medical collaboration	For example, a group of doctors sitting around a boardroom in Athens watching "live" or "recorded" a complex heart surgery conducted at the Baltimore Heart Center. Unlike watching a screen, you can choose to observe the operation in 3D from any angle. Unlike other technology, you can observe the patient from the inside using 3D captured data.
Architecture	For example, converting an architectural drawing and having it appear in 3D form right on your desktop. You can see the 3D building appearing in 3D in your real world, and then "fly" into the inside of the building and explore it floor by floor. Interior decoration can become so much more realistic and exciting when you can conduct a real 3D renovation.
Education	Books will take on a new meaning. Imagine reading "Alice in Wonderland" and having Alice chase the rabbit right before your eyes on the table.
Training	Throw away your Tai Chi textbook. Instead, follow your Kungfu Master in live 3D as she shows you how to do the Tai Chi in front of you.
Entertainment	Why go to London and watch Tom Jones perform at the London Palladium when you can watch Tom Jones "live" in 3D form right in your living room? Or the same technology could allow Tom Jones and a recreated late Elvis Presley perform together.

In addition to embodied and mixed reality, in terms of the important effects of interaction technology on entertainment, some of the main aspects we should consider are that computers and other devices are being networked together, supporting new forms of face-to-face and remote collaboration. Wearable and mobile devices are being developed that enable humans interact with each other, digital data and with their wide-space physical surroundings in a new futuristic manner. Perception and sensing technologies are being developed that allow the overlay of virtual imagery on the real world, so that both virtual and real can be seen at the same time to enable remote collaboration and play. These computing technologies are increasingly being used to support new forms of entertainment. Thus we should examine and consider entertainment as a strong form of communication, which can be enhanced using novel communication media. Instead of communication of raw information, for entertainment purposes we can expand our focus to communication of feelings and affect. Thus we should consider the novel aspects of feeling communication systems and how they can be used for entertainment computing systems, and this will be discussed in the next section.

1.3 Feeling Communication

Communication is one of the most fundamental needs and desires of most organisms, especially humans. Media has made advances in many ways in our networked age, for example, allowing communication over long distances including sound, voice, and text. The advent of the Internet, broadband, virtual worlds, and mobile devices allows remote communication through screens (providing audio/visual communication), even while on the move; however, we can have a lack of understanding of real feelings between the sender and the receiver. As described in previous research [19], the metaphor of communicating through a screen or window limits the sense of immersion and limits the ability for humans to communicate effectively. In traditional human communications, body gestures and touch [4] can sometimes more deeply explain the intended mind and provide intrinsic information, which makes for a more rich communication exchange. Furthermore, we often communicate emotionally using all the senses simultaneously, including sight, touch, sound, but also through taste and smell, such as sharing a meal together or cooking for a partner. We thus need to create fundamentally new forms of media to connect humans in the physical world and through the virtual world, not just in the transmission of information and verbal communication, but through meaning and nonverbal communication to increase the sense of telepresence using all the senses. This will allow more opportunities for people to make meaningful exchanges using media in both the physical and virtual world.

Feeling communication focuses on emotional communication that can deeply send our feelings and emotions to others. In other words, feeling communication does not only convey raw data or information, but also our deep feelings, intentions, expressions and culture. This will revolutionize the present digital communications and enhance social, business, and entertainment communication. We thus will examine various forms of feeling communication for that can create new forms of entertainment computing.

There will be various novel research trends and standards from the study of feeling communication. At the fundamental level, we need to develop new theoretical models of communication that unleash the potential for innovation in co-space communication from physical media through the virtual world. Human communication habits and preferences are continuously changing and evolving. A contemporary model includes the role of media and user context and provides for a model that recognizes the more complex context of the communication process and the possibilities of new media being truly extensions of man. Researchers need to go beyond this approach and focuses on human emotions, feelings, and nonverbal language

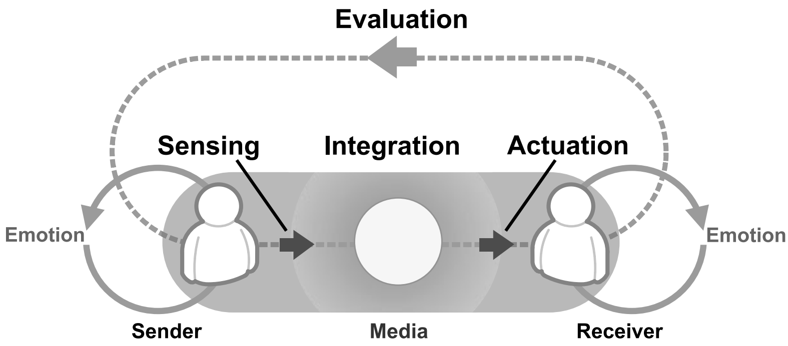

Fig. 1.1 Feeling communications

as key components in the communication process. Recent studies have helped illustrate that human senses are more acute and versatile than expected. For example, the studies show subjects using the sense of smell to determine the emotions of another person in much the same way as ants use pheromones [5]. This type of research is just beginning to unfold new mysteries of human perception and mind, which shows the potential for a new and more meaningful sense of presence with these new media technologies. Aside from the need for a new model of communication, we also look to improve the nature of human-to-human communication and entertainment, particularly through the co-space of physical and virtual world. The highly connected nature of people using the Internet also leads to our disconnectedness in physical social spaces, providing weaker links to general society and in some cases reducing the community and social aspects of life. We can improve this situation with corresponding new forms of entertainment and communication.

The main components in the design of feeling communication and entertainment systems are described below and summarized in Fig. 1.1.

Sensing This interaction is between the sender, the sender's environment and the media. The sensors can detect five sensory cues from the sender and her environment. An example is that the various sensors in the smart media can measure the sender's behaviors, intentions, and emotional changes.

Actuation This interaction is between the media and the receiver. The actuator can actuate certain sensory cues, which can represent the emotion or feeling of the sender, according the transmitted parameters. Following the example above, the smart media can make various visual, auditory, tangible, smell and taste expressions on it such that the receiver could also understand the meaning of those expressions.

Integration This interaction is between the sender and the receiver. This interaction needs the integration of human emotions and various expressions to understand the sender's and receiver's messages and emotional state.

To develop such a feeling communication and entertainment system, there are fundamental, theoretical issues that must be addressed, and a there is a need to refine the theory and provide insightful experimental results, user experience, and usability studies. Hence, the research issues which need to be examined through a combination of engineering, social science, and human computer interface studies include the following:

1.3.1 Emotional Communication and Entertainment Using Multi-sensory Media

In the world of co-space, physical presence takes a major role and it should dive into a new dimension of cutting edge technologies offering improvements to ordinary day-to-day feelings and experiences. We can use new technologies related to multimodal sensing and actuation to give the user more definition in their experience in the co-space environment. Visual, Auditory, Haptic, (Olfactory) Smell, and (Gustatory) Taste are the five sensors that humans use for environmental sensing, and emotional feeling communication. In addition to traditional communication through telephone and video-conferencing, the use of haptics, smell, and taste communication will enable a new paradigm of communication and have great research potential. Research into taste and smell communication has just begun to be explored in the field of human–computer interaction [3]. It is a field which still presents great technical challenges leading to early technical breakthrough results. We need to make use of these two senses for feeling communication media in combination with touch, sight, and sound, and enable users to utilize new media for conveying a sense of emotion. We can identify two main components in taste and smell communication: sensing and actuation.

Sensing of smell and taste is still in its early stages; researches have been conducted in the field, yielding promising results such as NASA JPL's electronic nose that uses 16 polymer sensors. Present research (Table 1.1) uses primary theories, for example, when a substance such as stray molecules from methane is absorbed into these films, the films expand slightly and there is a change in how much electricity they conduct. For actuation (Table 1.2), smell can be printed either in a 2D paper or in a 3D object using individually identified molecular components. It is possible to transmit smells and tastes over a distance, where it requires the exact composition of percentages to be transmitted.

The sensing of taste too takes a similar approach to the sensing of smell. There are five basic tastes a human perceives: sweetness, bitterness, sourness, saltiness, and umami. It is believed that these five tastes in various combinations make up different kinds of tastes that the human feels. Similarly, research in this field has come up with various solutions to identify taste such as those summarized in Table 1.3. Most of the current researches focus on a particular problem such as food quality control or beverage identification, etc., resulting in a limited range or number of chemicals to be identified. But for a next generation sensor, the contexts of use will include applications such as high fidelity human communication in which it is a great technical challenge to build a more general sensor that responds to a wide variety of tastes. Therefore, a new kind of taste sensor that uses an array of higher

Table 1.1 Smell sensing

Present state-of-the-art	Description	Next steps
JPL's ENose by NASA research and Electronic nose research at IIT [20]	Uses a collection of 16 different polymer films. These films are specially designed to conduct electricity. The sensor array "sniffs" the vapors from a sample and provides a set of measurements, pattern recognized with stored patterns for known materials	Develop systems to use a large collection of different polymer films to increase the sensing resolution. Also Frequency variation of a quartz oscillator can be used to accurately decide the different polymer types (a better way of identifying the polymers). The overall smell sensing subsection should be a very small-scale smell module which can be easily fit into a mobile phone
Electronic Nose Prometheus by Alpha M.O.S. [17]	The PROMETHEUS is the world's first odor and VOC analyzer that combines a highly sensitive fingerprint mass spectrometer	

Table 1.2 Smell actuation

Present state-of-the-art	Description	Next steps
Energi Print [9]	Energi Print has developed, in conjunction with international ink manufacturer Flint Ink, a genuine litho-varnish that has fragrance encapsulated within the varnish. It can print 10 different fragrances of flowers and plants	Develop a small-scale smell actuator or printer that can be used to actuate a vast variety of smells. The actuator could be electrical or chemical and perhaps inserted into the nose. Or the smell can be printed either in a 2D paper or in a 3D object using individually identified polymer components. Edible paper can be used where there is a need for smell and taste to be printed, and fragrance ink can be used for smell printing. Furthermore, develop a new kind of printer which is capable of printing graphics, taste and smell into edible paper, and which uses edible inks for smell and graphic printing
Olfactory display at ATR [25]	This work is more of a related work as it did not look at synthesizing the odor itself, however, it provided a very interesting method for a smell actuation interface which could be used with smell actuation systems, an olfactory display that does not require the user to attach anything on the face. The system works by projecting a clump of scented air from a location near the user's nose through free air. The system also aims to display a scent to the restricted space around a specific user's nose, rather than scattering scented air by simply diffusing it into the atmosphere. To implement the concept, the researchers used an "air cannon" that generates toroidal vortices of the scented air	

Table 1.3 Taste sensing

Present state-of-the-art	Description	Next steps
Electronic Tongue of the St. Petersburg University [23]	It uses an array of non-specific chemical sensor arrays to detect the taste of various liquids. The sensor module, hardware for A/D conversion and a PC for data processing are being used	Develop systems to use a large collection of different polymer films to increase the sensing resolution. Also Frequency variation of a quartz oscillator can be used to accurately decide the different polymer types (a better way of identifying the polymers). The overall smell sensing subsection should be a very small-scale smell module which can be easily fit into a mobile phone. Quantum steps in developing a taste sensor that is both miniature and of higher resolution to determine almost any taste are needed. The current status of research does not focus so much on the mobility of such a taste sensor. Research into developing a non-specific sensor array on a silicon wafer that could efficiently determine the composition of the chemicals to determine the taste
Electronic Tongue of the Cardiff University's School of Engineering [6]	It has an array of 5 chemical sensors to detect the 5 basic tastes. It has a 3 tier system similar to the one from the St. Petersburg University	

Table 1.4 Taste actuation

Present state-of-the-art	Description	Next steps
Chef Cantu's Canon Inkjet taste printer at the Chicago Restaurant [13]	This is a normal inkjet color printer that has been modified for taste printing with different edible ink cartridges on edible paper	Focus on miniaturizing the taste actuation process with a much higher precision and accuracy. New actuation media which could be direct electrical, or via liquid or edible paper media need to be invented. We can envision a taste sensor and taste printer that is attached to a mobile communication device that enables us unlimited seamless taste communication that would enhance our feeling communication
Food simulator at Tsukuba University [12]	The food simulator is a haptic device that simulates and actuates a biting force, while presenting auditory and chemical display at the same time. The device can present both food texture as well as chemical taste. The food simulator operates by generating a force on the user's teeth as an indication of food texture. Although the work was focussed on the haptic sensation of food rather than taste actuation, it can be combined with future taste actuation systems	

number of non-specific chemical sensors for a wide range of taste sensing should be developed. Thus, to add to this technical challenge is the immense effort to increase the resolution and the speed of response. In addition, such a device should be as small as possible to be easily integrated with a mobile communication device. For taste actuation also, the same principles can be applied. By identifying the chemicals that contribute to the five different tastes, we can mix and match them to produce the desired taste. As some research indicates, common printer technology can be used to print the tastes on edible paper (Table 1.4). The technical challenge here too remains in the miniaturization of such a device where careful research and design has to be spent on engineering such a device to suite the requirements such as the resolution of the sensed taste and also the speedy printing.

1.4 Social and Physical Entertainment

We have introduced the important paradigms of embodied media coupled with mixed reality, and the changing form of network communication for feeling communication and entertainment. We will now discuss in more detail some introductory concepts about why such techniques are important for the future generations of entertainment computing, especially to form social and physical connections through entertainment.

In pre-computer age, games were designed and played out in the physical world with the use of real world properties, such as physical objects, our sense of space, and spatial relations. Interactions in pre-computer games consisted of two elements: human-to-physical world interaction and human-to-human interaction. Nowadays, computer games have become a dominating form of entertainment due to their higher level of attractiveness to game players. There are some superior advantages which make computer games more popular than traditional games. Firstly, they attract people by creating the illusion of being immersed into imaginative virtual world with computer graphics and sound [1]. Secondly, the goals of computer games are typically more interactive than those of traditional games, which brings players stronger desire to win the game. Thirdly, usually designed with the optimal level of information complexity, computer games can easily provoke players' curiosity. Consequently, computer games intrinsically motivate players by bringing them more fantasy, challenge and curiosity, which are the three main elements contributing to the fun in games [14]. Finally, compared with many traditional games, computer games are also easier to play at any individual's preferred location and time. Thus, today's mainstream entertainment revolves around interactivity. People today enjoy entertainment they can control, and experience in which they are fully involved [26].

However, there is still a big gap to achieve physicality, mobility, tangible, social and physical interaction for people's entertainment. The development of computer games has often decreased their physical activities and social interactions. Computer games focus user's attention mainly on the computer screen or 2D/3D virtual environments, and players are bounded to the use of keyboards, joysticks, and the mouse while gaming. Although Nintendo Wii has been a breakthrough in terms of adding a more natural physical action to the video game play, the users are still basically standing or sitting in a spot and are focussed on a television screen. Thus in general, physical and social interaction is constrained, and natural interactions such as gestures, body language and movement, gaze, and physical awareness are lost [15].

Social interaction is critical as people not only want computer entertainment; they want to enjoy it together with family and friends. As shown in a survey [11], one of the top reasons why game players like to play games is that game playing is a social activity people can enjoy with family and friends. With advancement in networking technology, social gaming has gained popularity since the introduction of networked games [11]. Networked games overcame the barrier of distance, enabling real people play against each other over large areas. After all, there is no opponent like a live opponent since no computer model will rival the richness of human interaction [9]. According to a recent study by Nezlek [18], enjoyable and responsive interactions increase life satisfaction scores among people. However, a network game has a big deficiency because people cannot have physical interactions among each other. Natural interactions such as behavioral engagement and cognitive states are lost during entertaining. Addressing this problem, growing trends of nowadays games are trying to fill this gap by bringing more physical movements and social interactions into games while still utilizing the benefit of computing and graphical systems. In the commercial gaming area, the stunning success of the Nintendo Wii over the more technically advanced Sony Playstation and Microsoft Xbox has shown the general popularity of social and physical entertainment.

In future research systems, it seems that tangible mixed reality gaming has assumed a prominent role in fusing the exciting interactive features of computer gaming with the real physical world. An addition to the traditional paradigm offered by combining real and virtual worlds in entertainment is the notion of the social experience. Most of today's computer entertainment titles are multi-playing and draw their attraction between human competition and cooperation. However, since there are limitations of traditional human–computer interface, social interaction is still not an integral part of the entertainment experience. For example, with a traditional game, players cannot interact with each other in a natural affective fashion, but communicate each other through a computer screen or microphone. And also all actions they play on each other are implemented by keyboard or mouse, or joy-controller. Natural human interactions such as gestures, physical movement, tangible touch, gaze and eye contact, and communication such as with smell are lost in the game. The social experience is not just about providing multi-player experiences where the user's can compete and collaborate with each other, but also have to further augment the strong emotional involvement among the players by introducing direct social face-to-face and feeling communications as well as new interfaces between the players and the virtual domain.

In the subsequent parts of the book, some blue sky research examples of mixed reality entertainment which give players more compelling experiences of physical, virtual and social interactions in the future of entertainment systems will be presented. In order to regain natural interactions, mixed reality technology and feeling communication have great potential for promoting social and physical interactions in entertainment. Such systems are a novel form of entertainment that anchors on physicality, mobility, tangible, social and emotional interaction, and ubiquitous computing. With these systems, there are three main features: Firstly, the players physically and immersively role-play in the game, playing as if a fantasy computer digital world has merged with the real physical world. Secondly, users can move about freely in the real world, whilst maintaining seamless networked social and emotional contact with human players in both the real and virtual world. Thirdly, such systems also explore novel tangible aspects of physical movement and perception, both on the player's environment and on the interaction with the digital world.

Physical interaction allows a psychological advantage in that players immerse themselves from the real world to virtual world effectively. Players should keep a mental model of the action in real world when they jump into the virtual environment. Physical interaction thus should be a fundamental element for the next generation entertainment. Together with the highly dynamic nature of computer simulations, the upcoming use of the multi-sensual presentation capabilities of entertainment technology has the potential to provide much more inversive and richer gaming situations than those of the present gaming systems.

With social and physical interactive paradigms, the new hybrid application will open a new page for computer entertainment. In subsequent chapters, we will discuss these ideas, systems, and projects in detail in terms of their motivations and requirements of the particular application domain, their system description and design decisions, as well as their future impacts on the human social and physical entertainment field.

In Chap. 2, Human Pacman, based on the original Pacman video game, is an outdoor gaming system where players take the role of Pacman and Ghost physically, and interact in a physical–virtual environment through custom-built wearable computers. Human Pacman emphasizes the importance of physical activities and human–human relationship in a future entertainment system.

The Human Pacman is an example of augmented reality entertainment, where the virtual world is embedded in the physical world, whereas in Chap. 3 we examine augmented virtuality entertainment, where the physical world is captured and embedded in the virtual world. The described 3D-live system is used for making an interactive theater that combines the live human capture, spatial sound, augmented reality, human-oriented interaction, and ambient intelligence technologies. Users can interact tangibly with their or their friends' 3D live avatars, which leads to a special kind of self-reflection and offers a new form of human interaction.

Interactive media should be aimed to enhance not only human-to-human communication, but also human-to-animal communication. Thus in Chap. 4, a new type of inter-species media interaction is described, which allows human users to interact and play with their small pet friends (in this case, hamsters) remotely via the Internet through a mixed reality based game system. The system called "Metazoa

Ludens" is an example of mixed reality entertainment computing, forming a new kind of human-to-animal communication.

Entertainment is a form of empathetic communication, and it can also be used to enhance warm communication between humans and animals. Being a cross-section of haptics, cybernetics, tangible interaction and remote communication, Poultry Internet described in Chap. 5 is a human–computer–pet interaction system that transfers the human contact through the Internet to the pet, and simultaneously transfers the pet's motion in real time with a physical dolls movement. This system emphasizes and enhances the human–pet relationship which is under-estimated severely in our modern society.

Another positive advantage of entertainment computing is to enhance communication of young and elderly, especially in our modern world with rapidly aging population. To enhance inter-generation relationship between the elderly and young, Chap. 6 presents the Age Invaders project. Like Human Pacman which brings standard computer games into the real world, Age Invaders requires and encourages physical body movements rather than constraining the user in front of computer for many hours. More importantly, the game offers adaptable game parameters to suit the simultaneous gaming of elderly and young so that they can play harmoniously together. This unique feature of Age Invaders helps to strengthen the intergenerational bond significantly and promotes mental and physical activity through mixed reality entertainment.

With more and more time being spend in the virtual world, we are often isolating ourselves from the real world where actual physical touch is very important as a communication means. Touch is able to signal deeper meanings than words alone, and is an essential non-verbal and non-logical communication. Entertainment and play can enhance non-verbal and indirect communication. In Chap. 7, a novel wearable system aimed at promoting physical interaction in remote communication between parent and child is discussed. The system "Huggy Pajama" enables parents and children to hug one another through a hugging interface device and a wearable, hug reproducing pajama connected through the Internet.

Another positive use of entertainment computing is to promote deep culture by creating new forms of entertainment media which combine traditional culture with modern entertainment media. Young people often prefer new entertainment and social media, and this we can allow them to explore culture through a novel merging of traditional cultures and literature with recent media literacy. New forms of cultural computing systems are thus presented in Chap. 8.

Entertainment can be a great tool to promote happiness and comfort in all ages and cultures, and this can be aided by the soft power of cuteness. Chapter 9 describes the importance of cute or kawaii culture in entertainment, popular culture, and interactive media. Cuteness in interactive systems is a relatively new development, yet has its roots in the aesthetics of many historical and cultural elements. We provide an in depth look at the role of cuteness in interactive systems by beginning with a history. We particularly focus on the Japanese culture of kawaii which has made a large impact around the world, especially in entertainment, fashion, and animation. We then take the approach of defining cuteness in contemporary popular perception. This knowledge provides for the possibility to create a cute filter which can transform inputs and automatically create more cute outputs. The development of cute social computing and entertainment projects are discussed as well.

In our busy urban lives, we need to have short bursts of fun to relieve stress no matter where we are. Entertainment includes "fun" in our everyday life activities, from meeting friends to relaxing at hot spas. Everyday artifacts can become entertaining media if these artifacts and environment are designed to be responsive. Chapter 10 discusses the researches of entertaining artifacts to share how to design responsive artifacts for entertaining experience in our everyday life.

Chapter 11 describes a new form of combining physical and virtual entertainment on the tabletop. The video game industry is constantly searching for new ways to convert non-players into dedicated gamers. Despite the growing popularity of computer-based video games, people still love to play traditional board games, such as Risk, Monopoly, and Trivial Pursuit. Both video and board games have their strengths and weaknesses, and an intriguing conclusion is to merge both worlds. We believe that a tabletop form-factor provides an ideal interface for digital board games. The design and implementation of tabletop games will be influenced by the hardware platforms, form factors, sensing technologies, as well as input techniques and devices that are available and chosen. This chapter describes the most recent tabletop hardware technologies that have been used by tabletop researchers and practitioners, discusses a set of new experimental tabletop games and presents ten useful evaluation heuristics for tabletop game design.

1.5 Conclusion

It has been argued that entertainment is a key driver for development of technology, and it is proposed to use embodied interaction between humans and computation both socially and physically, with the aim of novel interactive computer mixed reality entertainment. Social and physical interactive paradigms for mixed reality involve the elements of ubiquitous computing, tangible interfaces and interaction, as well as social computing. They bring the opportunity of interaction and entertainment through and with the environment, rather than only on a desktop computer with keyboard and mouse, in addition to incorporating the sociological organization of interactive behavior and a deeper feeling communication. Thus, with social and physical interactive paradigms, people can easily play and entertain with each other and computers within the real and virtual world. Essentially, humans as physical beings now actually become situated inside the computational world.

The background of social and physical interactive paradigms was discussed, and in the later sections of this book, more detailed research and analysis will be shown, where the users have interactions both socially and physically by computing within the physical environment. Moreover, these activities take place in the context of the environment. Using 3D graphical objects, tangible interaction, and 3D sound, ubiquitous computing allows the manipulation of objects in physical space to interact with digital information. For these systems, the computer is embedded in the activity in such a way that the user interacts with the environment, and physical objects themselves become the interface.

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Chapter 2
Human Pacman: A Mobile Augmented Reality Entertainment System Based on Physical, Social, and Ubiquitous Computing

2.1 Introduction

In recent years, the world has seen the proliferation of highly portable devices, such as personal digital assistants (PDAs), laptops, and cellular telephones. At the same time, trends in computing environment development suggest that users are gradually freed from the constraints of stationary desktop computing with the explosive expansion in mobile computing and networking infrastructure. With this technological progress in mind, we have developed Human Pacman which serves as a pioneer in the new genre of computer game that is based on real-world-physical, social, and wide area mobile-interactive entertainment. The novelty of this computer game has the following aspects: Firstly, the players physically and immersively role-play the characters of the Pacmen and Ghost, as if a fantasy computer digital world has merged with the real physical world. Secondly, users can move about freely in the real world over wide area indoor and outdoor spaces whilst maintaining seamless networked social contact with human players in both the real and virtual world. Thirdly, Human Pacman also explores novel tangible aspects of human physical movement and perception, both on the player's environment and on the interaction with the digital world. In other words, objects in the real world are embedded and take on a real-time link and meaning with objects in the virtual world. For example, to devour the virtual "enemy", the player has to tap on the real physical enemy's shoulder; to obtain a virtual "magic" ingredient, the player has to physically pick up a real physical sugar jar with an embedded Bluetooth device attached.

In this system, players are provided with custom-built wearable computers, and they interact both face-to-face with other players when in proximity or indirectly via a wireless LAN network. Also fully utilizing the high computing power of wearable computers and the underlying network support, Human Pacman takes mobile gaming to a new level of sophistication by incorporating virtual fantasy and imaginative play activity elements that have made computer game popular [21] with the implementation of Mixed Reality on the Head Mounted Displays (HMD). The players also experience seamless transitions between real and virtual worlds as they swap between immersive first person augmented reality view (with virtual cookies in the real world) and full virtual reality view of the Pac-world throughout the game.

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Another important feature of Human Pacman is its inherent support of networked mobile gaming. Mobile gaming is already a big business in Japan and South Korea where up to 70% of users on some networks regularly use the service [7]. According to Forrester Research [31] of the US, within three years 45% of European mobile subscribers will regularly play games on their mobile phones. London-based Ovum [14] forecasts that global spending on mobile games will reach €4.4 billion by 2006. Well-known mobile entertainment success stories in Japan include NTT DoCoMo's IMode. Games that it carries, such as Sega's Space Harrier and ChuChu Rocket, will bring in nearly US $830 million this year (Source: Datamonitor). As will be shown below, Human Pacman takes mobile entertainment to a new level of interactivity through its emphasis on seamlessly merging the physical real world with the virtual world, maintaining networked social contacts through out and across the real and virtual world boundaries, and emphasizing physical and tangible contacts with the digital world.

Björk suggested ubiquitous games as a new form of gaming [4]. A ubiquitous game is a game that explores the use of ubiquitous computing (ubicomp) [36] as defined by Weiser. He painted a picture where computers would be embedded in everyday object, and computing is invisible because there is "intelligent" communication between the objects. Employing this philosophy, we have implemented a system that embeds everyday physical objects, which seamlessly take on a digital fantasy meaning, throughout the wide area real-world environment. For example, we have attached Bluetooth devices to sugar jars which when being picked up, will automatically communicate with the wearable computer by adding the corresponding virtual ingredient to the inventory list of the player.

Human Pacman ventures to elevate the sense of thrill and suspended disbelief of the players in this untypical computer game. Each of the novel interactions mentioned is summarized in Table 2.1. We will proceed with details to Human Pacman by firstly giving a research background to this system and previous works that have motivated us. Then we proceed to detail gaming experiences involved by clarifying the actual game play designed. We venture to explore the intricate issues of interaction versus experience in mobile mixed reality gaming that arise between physical mobile players together with virtual online players in this game. We study and elaborate on the impacts of mixed reality gaming on users' experience arising from a unique combination of physical, virtual and social interactions. We also demonstrate how this novel form interactions provide entertaining and fulfilling sensations and present our user study results to support our arguments. After that we will discuss the various mobile service issues with respect to the system; as well as analyze the system in the context of addressing various ubicomp concerns. Lastly, we conclude with our reflections on the future impacts of the system on everyday life.

2.2 Background

Today's mainstream entertainment revolves around interactivity. Gone are the days when people were satisfied with passive form of entertainment as provided by television and cinema. People today enjoy entertainment they can control, and experience

Table 2.1 Detailed feature descriptions of Human Pacman

Feature	Details
Physical gaming	Players are physically role-playing the characters of Pacmen and Ghost; with Wearable Computers donned, they use free bodily movements as part of interaction between each person, between the real and virtual world, and among objects in the real wide area landscapes and virtual environments
Social gaming	Players interact both directly with other players when they are in physical proximity, or indirectly via the wireless LAN network by real-time messaging. There is a perfectly coherent networked social contact among players in both the real and virtual worlds, as well as throughout their boundaries. People from all around the world can also participate in the Human Pacman experience by viewing and collaborating in real time over the Internet with the physical Human Pacmen and Ghosts who are immersed in the physical real world game
Mobile gaming	Players are free to move about in the indoor/outdoor space without being constrained to the 2D/3D screen of desktop computers
Ubiquitous computing	Everyday objects throughout the environment seamlessly have a real-time fantasy digital world link and meaning. There is automatic communication between Wearable Computers and Bluetooth devices embedded in certain physical objects used in game play
Tangible interaction	Throughout the game people interact in a touch and tangible manner. For example, players need to physically pick up objects and tap on the shoulder of other players to devour them
Outdoor wide-area gaming arena	Large outdoor areas can be set up for the game whereby players carry out their respective missions for the role they play. This could even be linked throughout cities
Seamless transition between real and virtual worlds	Players swap freely between the immersive first person augmented reality view (with virtual cookies and instructions overlay the real world) and the full virtual reality view of the Pac-world in the game

in which they are full involved [39]. In fact, not only do they want such entertainment; people want to enjoy it together with family and friends. As shown in a survey [11], one of the top reasons why game players like to play games is that game playing is a social activity people can enjoy with family and friends. With advancement in networking technology, social gaming has gained popularity since the introduction of networked games [11]. Networked games overcame the barrier of distance, enabling real people to play against each other over large areas. After all there is no opponent like a live opponent since no computer model will rival the richness of human interaction [9]. According to a recent study by Nezlek [22], enjoyable and responsive interactions increase life satisfaction scores among people. Nevertheless, even in networked computer games, social interaction between players is limited since natural interactions such as behavioral engagement, and cognitive states are lost. Thus, by bringing players in physical proximity for interaction, Human Pacman brings networked social computer gaming to a new ground because humans enjoy being physically together, and socially interacting with each other [5]. Essentially, Human Pacman brings the exciting interactive aspects of networked gaming, and merges it with the real physical world, to allow a seamless real-time networked social contact between humans in both the real and virtual worlds simultaneously.

Human Pacman has also aspects derived from pioneering work that has been developed on ubiquitous gaming. Multi-players mobile gaming is demonstrated in 'Pirates!' [3]. 'Pirates!' implements the game on PDAs with proximity sensing technology to incorporate a player's contextual information (such as physical co-location of players and objects in the world) into the game context as important elements of the game mechanics. However, visual and sound effects of game play are limited by relatively low computing power of PDAs. Augmented Reality and Virtual Reality cannot be implemented; therefore, immersive experience is rather limited due to the flat 2D display used on PDAs. The E3 project [18] examines the essential elements of free play, and multi-user social interaction. It focuses on human-to-physical interaction and human-to-human interaction. However, it does not explore large-scale configuration where users walk around.

Human Pacman has its roots in serious research about people's interaction with their world. People as social creatures find physical interaction, touch, and human-to-human presence essential for the enjoyment of life [5]. We remember that in pre-computer age, games were designed and played out in the physical world with the use of real world properties, such as physical objects, our sense of space, and spatial relations. Nowadays, computer games focus the user's attention mainly on the computer screen or 2D/3D virtual environment, therefore constraining physical interactions. However, there seems to be a growing interest in physical gaming and entertainment. Commercial arcade games have recently seen a growing trend of games that require human physical movement as part of interaction. For example, dancing games such as Dance Dance Revolution and ParaParaParadise [16] are based on players dancing in time with a musical dance tune and moving graphical objects (see Fig. 2.1). However, these systems still force the person to stand at more or less the same spot, and focus on a computer screen in front of them. Nevertheless, our underpinning philosophy is similar. One of the goals for Human Pacman is to bring physical gaming into computer entertainment.

Even though Human Pacman uses augmented reality techniques as part of its interface, it is only for providing a comprehensive user interface for the players. There were some previous works done on using augmented reality in entertainment. AR2 Hockey [24] is a system that allows two users to hit a virtual puck on a real table, as seen through a HMD. AquaGaunlet [33] is a multi-player game where players fight with strange invaders coming from the virtual world through some egg-shape objects into the physical space. These games are played in a small and restricted area, with limited movement, and little interaction with physical space. The games have no transitions between AR and VR. There is also no exploration on the physical environment the player is in. Another important mobile game is known as ARQuake [34], which is an AR extension of the popular computer game Quake. Using Wearable Computer equipped with global positioning system, ARQuake can be played indoor and outdoor. However, it is a single player game with practically no social interaction.

Fig. 2.1 A player at the ParaParaParadise arcade game

Lastly, the transitions between the real and physical world in Human Pacman are derived from research that has been done on continual transversal along the Reality–Virtuality continuum [19]. The Magic Book [2] uses a book metaphor to demonstrate the seamless transitions between augmented and virtual reality. Collaboration is carried out only in a small-scale and closed-up configuration. Touch-Space [6] is an embodied computing based mixed reality game space with free movement between the real world and virtual world. Players are tracked with inertial-acoustic hybrid tracking devices mounted on the ceiling. However, since they are restricted to a small indoor area, there is limited physical movement in game play. In Human Pacman, the interface and transition between the real world and virtual world is achieved in real time throughout the spacious indoor and outdoor physical world.

2.3 System Design and Game Play

Human Pacman features a centralized architecture that is made up of four main entities, namely the central server, wearable computers, laptops, and Bluetooth embedded objects. An overview of the system is shown in Fig. 2.2.

The wireless LAN serves as a communication highway between the wearable computers, the helper computers (laptops), and the server desktop computer. The underlying program is built on a client–server architecture with wearable computers and helper laptops as clients, and the desktop computer as a central server. Physical location and players' status updates are done between the client wearable computers and the server on a frequent and regular basis. The server maintains up-to-the-

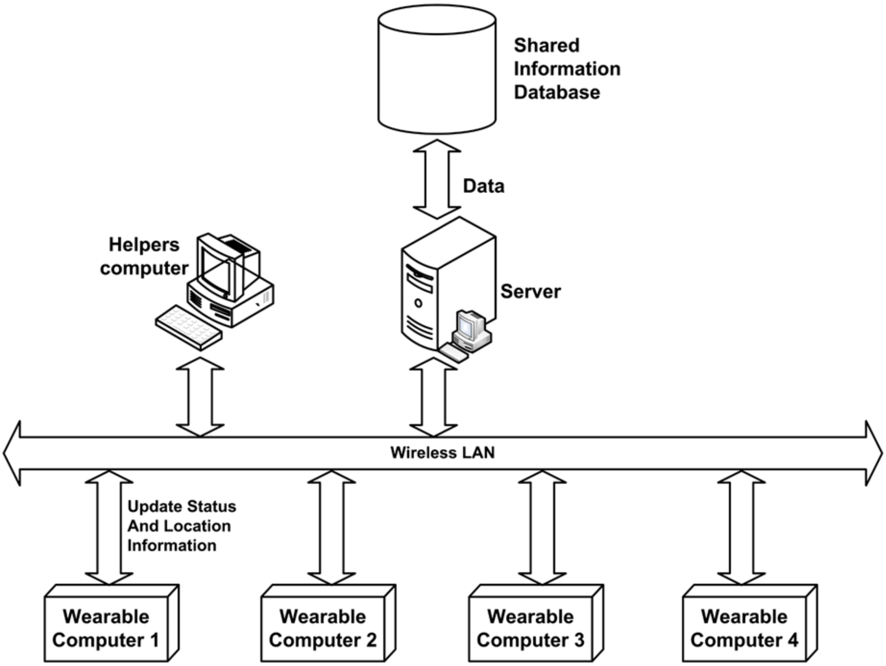

Fig. 2.2 Top level system design overview of Human Pacman

minute players' information (location, status, etc.), and presides over any communication between Bluetooth objects and the wearable computers. The wearable computers were developed in the lab and the main components are a Single Board Computer, Twiddler2 (handheld keyboard and mouse), Cy-Visor Head Mounted Display (video see-through HMD) with FireWire camera attached, InertiaCube2 (inertia sensor from Intersense), and DRM-III module (GPS and Dead-Reckoning device from Point Research Corporation).

With the software architecture mentioned as the backbone of the game engine and the hardware as enabling tools, we proceed to describe the game play of Human Pacman. The main concepts of the game are first given in terms of team collaboration, ultimate game objectives, and essential nature of the game's playground named Pac-world. Then, we move on to present the details on the players' roles as Pacman, Ghost, and Helper, respectively. We end this section by giving examples on several actual game play situations.

2.3.1 Main Concepts: Team Collaboration, Ultimate Game Objectives and the Nature of Pac-world

The players are assigned to two opposing teams, namely the Pacman team and the Ghost team. The former consists of two Pacmen and two Helpers; correspondingly,

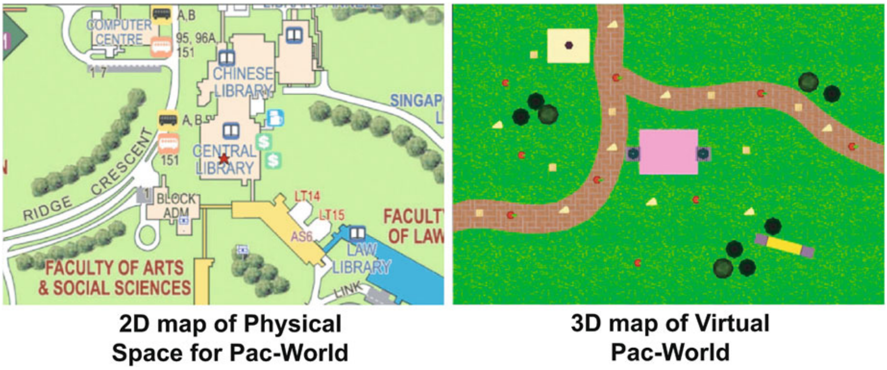

Fig. 2.3 2D map of game area and its corresponding 3D map of Pac-world

the latter consists of two Ghosts and two Helpers. Each Pacman/Ghost is in coalition with one Helper, promoting collaboration and interaction between the users. Since a Helper player is essentially participating in the gameplay remotely using a computer terminal over a wireless LAN, Human Pacman can effectively be expanded to include online players anywhere on Earth who can view and collaborate via the Internet with real human Pacmen and Ghosts who are immersed in the physical playground.

Ever since its introduction by Namco to Japanese arcade fans in 1979, Pacman has gone through numerous stages of development, yet the ultimate goal of the game remains fundamentally unchanged. We have designed Human Pacman to be in close resemblance to the original Pacman in terms of game objectives so that the players' learning curves are very much leveled to the point that they can pick up the game in no time and enjoy the associated familiarity. Basically, the goal of the Pacman team is to collect all virtual plain cookies and hidden ingredients in Pac-world while avoiding the Ghosts. On the other hand, the aim of the Ghost team is to devour all Pacmen in the Pac-world. To add to the excitement of game play, after 'eating' certain special ingredients, a Pacman gains Ghost-devouring capability, and henceforth can attack her enemy head on for a limited period of time.

Pac-world is a fantasy world existing dualistically in both Augmented Reality (AR) and Virtual Reality (VR) mode. Pacmen and Ghosts, who are walking around in the real world with their networked wearable computers and head mounted displays (HMD), are allowed to switch between the two viewing modes. Helpers, on the other hand, can only view in VR mode since they are stationed in front of networked computers. Most importantly, there is a direct and real-time link between the wide-area physical world and the virtual Pac-world at all times, thus providing the users with a ubiquitous and seamless merging of the fantasy digital world and the realistic physical world. As seen in Fig. 2.3 where the 2D map of the selected game play area in our university campus and the 3D map of Pac-world are shown side-by-side, we have converted the real world to a fantasy virtual playground by ingraining the latter with direct physical correspondences. This is done with the help of the Dead Reckoning Module (DRM) and inertia sensors.

The DRM is an electronic module comprising a 12-channel Global Positioning System (GPS) receiver, digital compass, pedometer, and altimeter. The DRM measures the displacement of the user from an initialization point by measuring the direction (with data obtained from the compass), and distance traveled (using accelerometer data) with each footstep taken. Although the DRM is a self-contained navigation unit, when GPS position data is available, it can be used to correct both the distance and direction calculations with the help of a Kalman filter algorithm. Besides, in conjunction with the step detection logic (pedometer), the module can detect running, sideways, and backwards walking which is necessary for our application.

InertiaCube2 is used for head tracking for the implementation of augmented reality display in the HMD. Since augmented reality is implemented as an interface feature between the players and their wearable computers, head tracking for the calculation of view perspective of each player is important. It is an inertial three degree-of-freedom orientation tracking system that gives yaw, pitch and roll of the object that it is attached on. By placing the sensor on the cap of each player, her head movement and orientation is tracked to high accuracy. Consequently using the player's position and head movement, the wearable computer calculates the relative position of each plain cookie within the view of the camera, and superimposes a 3D virtual cookie image of a proportionate size on corresponding position on the video stream. The position of other mobile players obtained from the server is used to update the 2D virtual map in the HMD view of the player. Similarly, the point-of-view of each mobile player is sent to the computer of a helper through the server, and the corresponding view in the virtual Pac-world can be displayed.

The real-time position of each mobile user is sent periodically to the server through wireless LAN. Upon receiving the position data, the server sends an update to each wearable computer with the position of other mobile players, as well as the positions of all "non-eaten" plain cookies.

The position of a player with respect to another player or location in the physical world is calculated as follows. Taking two physical locations as $point1$ and $point2$, the distance d between $user1$ and $user2$ in radian can be calculated by:

$$d = \cos^{-1}\left\{\sin(lat1)\sin(lat2) + \cos(lat1)\cos(lat2)\cos(lon1 - lon2)\right\}, \qquad (2.1)$$

where $lon1$, $lat1$, $lon2$ and $lat2$ are the longitude and latitude of $user1$ and $user2$, respectively, which all are in radians. To compute the distance in kilometers instead of radians, d is multiplied by the radius of the Earth, which is estimated at 6,371.0 km.

The course $c12$ from $user1$ to $user2$ will be:

IF $\sin(lon2 - lon1) < 0$

$$c12 = \cos^{-1}\left\{\frac{\sin(lat2) - \sin(lat1)\cos(d)}{\sin(d)\cos(lat1)}\right\} \qquad (2.2)$$

Fig. 2.4 First person view of Pacman

ELSE

$$c12 = 2\pi - \cos^{-1}\left\{\frac{\sin(lat2) - \sin(lat1)\cos(d)}{\sin(d)\cos(lat1)}\right\}. \tag{2.3}$$

The above $c12$ is valid when the $user1$ is facing to the North Pole. Otherwise the yaw of the North Pole for the $user1$ must be subtracted from $c12$.

2.3.2 Pacman and Ghost

Human Pacman offers physical interactions with themes found not dissimilar in sports and childhood games such as rugby and hide-and-seek. The element of physicality is emphasized to explore a new experience in mixed reality gaming played in the city streets.

Pacman has to physically move around the game area attempting to collect all virtual cookies. When she is in AR mode, through the HMD, she sees the real world being overlaid with virtual plain cookies as shown in Fig. 2.4. Unlike in PacManhattan [25] where the physical players could only envision the imaginary cookies in their mind, physical players in Human Pacman can view the cookie from the first person point of view. Despite the virtuality of the cookies, the body action of moving through them in order to obtain the cookie provides a realistic sensation of physical–virtual interaction. This is further enhanced by the audible “chomp” sound that would alert the player to signify successful collection.

In addition to the virtual plain cookies, she has to find and collect physical ingredients that are actually Bluetooth embedded objects as shown in Fig. 2.5. Unlike in Mogi [20], where players will be moving in an outdoor area and pick up virtual

Fig. 2.5 Bluetooth embedded object

items through their mobile phone interface (by pressing buttons), the Human Pacman not only has to find the real Special Cookie, but also to hold the box physically in order to gain the Super Pacman skill. These objects have direct links and representations in the virtual Pac-world. This provides a sense of presence and immersion with the virtual Pac-world, as well as a feeling of actively participating in the game in the real world.

On the other hand, Pacman should avoid being devoured by Ghost, i.e., not letting Ghost tapping on her shoulder where the capacitive sensor is attached on. This physical touch interaction between the players exemplifies tangible physical interaction between humans, which is commonly found in traditional games such as hide-and-seek and the classic "catching" game, but is now being revived in a computer gaming arena. Similarly, Pacman gets to do the same after becoming Super Pacman. Hence, Human Pacman demands more physical involvement from both parties, resulting in a more exciting and engaging game play.

The role of a Ghost is rather straightforward; she has to track down all Pacmen and devour them. Nevertheless, she has to beware of Pacmen with Ghost-devouring power and avoid being devoured by them.

It must be noted that when Pacman or Ghost switches to VR mode, she is completely immersed in the virtual Pac-world. However, virtual paths are drawn in close correspondence to roads in the real world as seen in Fig. 2.6. Despite being physically separated from one another and highly mobile, each player is constantly tracked and her identity as unique entity in Pac-world is maintained in real time.

Searching is yet another important activity for both players; be it Ghost searching for Pacman, or the other way round when Pacman has become Super Pacman. Since players are facing the real opponents instead of computer artificial intelligence created ones, the hunted real players will be definitely seeking smarter ways to evade and hide in ways that would not be required with present console or PC based computer games. On top of that, Pacman needs to search for cookies and hidden special cookies as well. The physical process of searching consequently demands coordination between players' movements, observations and reactions to the immediate environment. For instance, an observant Ghost could even trail the physical path of the Pacman in the real world through the disappeared cookies that were seen earlier. Players are thus constantly being challenged

Fig. 2.6 Correspondence between the physical world and virtual Pac-world

to inquire further into the actual physical neighborhood area within finite period of time.

The physical interaction, however, does have its limitations and shortcomings in the context of providing a fulfilling and entertaining experience for players. In examining physical interactions in Human Pacman, we have merely focused on users using their body movements to stay engaged in the game. While contact in terms of competition exists between both parties, collaborations is lacking. As the law of physics binds every player to the ground, collaborations between members of same team could prove to be too difficult when they are physically far apart.

Of course, we can seek ways to enhance the cooperation between the physical players, for instance, using voice for long distance communication through a walkie-talkie or mobile phone. However, it would be more interesting if we could bring in another kind of player who is not being restricted by the physical world limitations to participate in the game. The new interaction between the original physical players and this new type of players should be refreshing and could spark off more interactive innovations. In the light of this, we introduce a new virtual team member – the Helper – as a new genre of player which we will elaborate further in the next section.

2.3.3 Helper

Helper is a new character in Human Pacman who does not exist in the original Pacman game. This new role is created to enhance the game by contributing an alternate means of hybrid interaction between the real and virtual players. In this context, being a virtual player implies that the participation of the Helper does not take into account of her physical presence relative to the actual location of Pacman

Fig. 2.7 Close collaboration between Pacman and her Helper

and Ghost. She could connect to the game server from almost anywhere in the world through the Internet. Each Pacman and Ghost will be assigned a partner Helper who acts as an intelligence advisor and coordinator in her quest for achieving the goal. Helper, who is always in the VR mode and sees all, guides her partner by messaging her with important information as shown in Fig. 2.7, and thus this promotes collaboration and interaction between humans.

We have integrated the elements of situated actions into the role of Helper. For instance, one of the exciting virtual interaction features is the ability of Helper to watch the game in a unique way. A football game or a TV show normally can only allow viewers to accept passively whatever is shown. However, here we allow Helper to view the game "live" in virtual reality form anywhere through the Internet from any angle and distance. Every movement in the physical world will be reflected immediately in the virtual realm. Even when Pacman becomes Super Pacman, Helper would see a corresponding change in the 3D graphic model. This mode of virtual viewing (watching the real live event in alternate graphical form) provides a new dimension of watching experience for participants, which is both efficient and entertaining.

Helpers, however, are not restricted to watching the game passively. They can actually communicate with Pacman or Ghost in real time via text messaging bidirectionally. While Helpers use computer keyboard for text-inputting, Pacman and Ghost communicate and respond to their Helpers in the chat by using the Twiddler, a handheld inputting device. The communication that takes place could be either a casual chat or a discussion on the winning strategy. Such interactions could promote social cooperation and establish relationships between humans who are operating across radically different contexts.

From the viewpoint of Helpers, while communicating and watching the Pacman/Ghost avatar move around, they should realize that it is different from other common online games; both Pacman and Ghost are actually bodily moving somewhere in the physical world, and are not just any other players who sit in front of the computer screen like them. Every piece of information they can provide matters as it can consequently affect the physical player's next movement in the actual location which Helpers can see virtually. Also Helper cannot ask physically impossible movements, for example, to move from one street to another in too short a time.

From another perspective, with the assistance of Helper, Pacman/Ghost will be having a guardian watching over her, even though the identities or whereabouts of Helpers might be unknown. It would be as if they possess an extra pair of eyes roaming in the sky (like a bird) aiding and advising them. For an outdoor wide area game such as Human Pacman, a human's assistance would definitely prove to be more useful than some raw numbers to pinpoint the player to her current coordinates.

As the complexity of the game in terms of area space or number of Pacman/Ghost players is increased, we foresee social interaction among players should be even more active and necessary. The role of Helper is more critical in these cases, in order to support the players by providing even more knowledge on the current states and brainstorming for the next move or strategies with limited resources available.

To a great extent, the existence of Helpers for both teams resulted in a powerful synergy of interaction between real and virtual domains in the social context of mixed reality gaming. Collaboration within each team becomes more effective despite being bridged by only text messages. Winning or losing largely becomes a function of teamwork, and this adds a greater thrill and fun factor to the game as a whole. In short, the introduction of the role of Helper certainly enriches the interaction theme of Human Pacman.

Figure 2.8 shows the overall picture for the different forms interactions that we have discussed so far. In the figure, Pacman is assisted by her Helper, who is sitting in front of a screen. The screen is displaying the virtual Pac-world, which is in direct real time correspondence to the real world. Similarly, Ghost is also assisted by a different Helper. As both Helpers are able to see positions of Pacman, Ghost, virtual cookies and Bluetooth cookies in the Pac-world, they can guide Pacman or Ghost by using text-based messaging to achieve their ultimate goal of winning the game.

2.3.4 Actual Game Play

Starting the Game Pacmen and Ghosts start from the Pac-castle and Ghost-house in Pac-world, respectively. These two places correspond to two different physical locations in the game area.

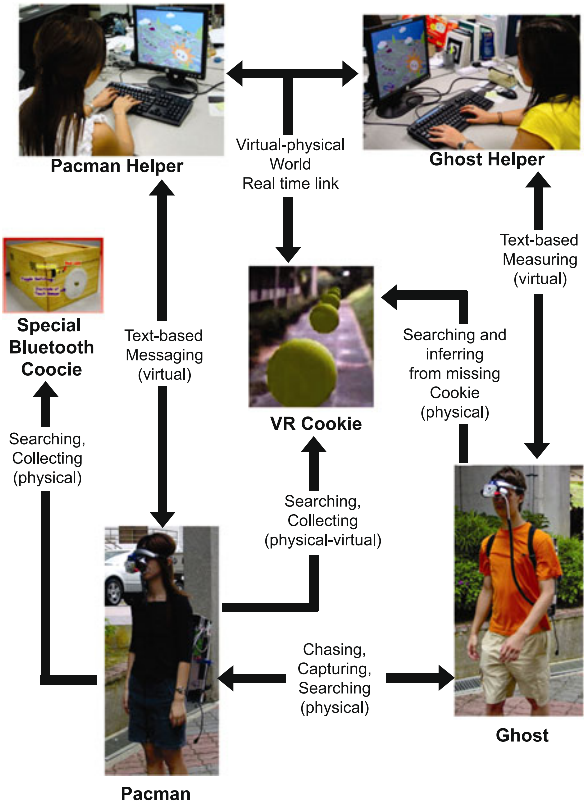

Fig. 2.8 Overall game flow in Human Pacman

Collection of Plain Cookies Pacman collects a cookie by walking through it. Such physical action is reflected visually in Pac-world through the disappearing of the cookie in both the AR and VR modes. The collection of cookies by a Pacman will be reflected in the Pac-world map seen by all players in real time, be it on the player's HMD or the Helper's laptop. In Fig. 2.9, the top images show the HMD view of the Pacman player as she collects a cookie. When she walks through the cookie, the cookie disappears. Note that this is also reflected in the virtual Pac-world in real time by the disappearing of the cookie at the corresponding location. This is shown in the images of the figure.

Ghosts are not allowed to collect cookies. Although a Ghost is not able to see enemy Pacman on the map, the disappearing of cookies in her map can give her a hint to where to find a Pacman. Therefore, Pacman has to be careful as her physical interaction with the real world (i.e., movement) can be digitally reflected in the virtual world, and be used by a Ghost. Novelty is again seen in such intimate relationship between interaction in the physical world and its effect in the fantasy virtual world. Neither physical distance nor mobility could restrict each player from seeing this

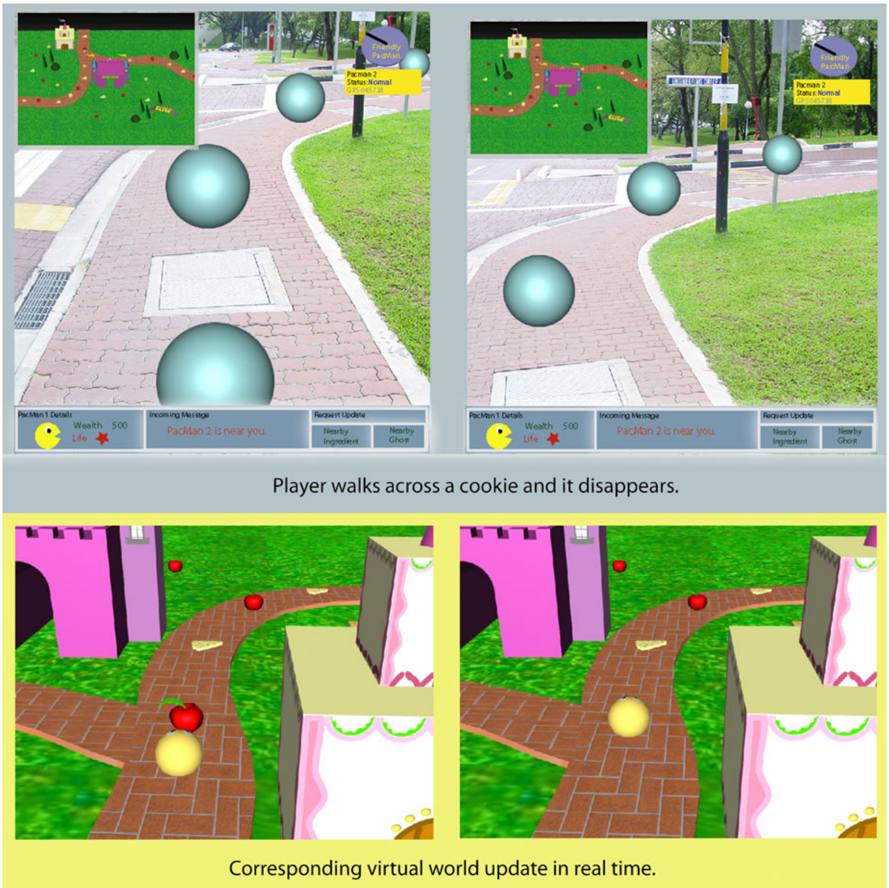

Fig. 2.9 Pacman collecting cookies

effect real-time as all players, including Ghosts can see an update of the virtual map in real-time.

Collection of Ingredients In the game, Pacmen collect ingredients to make special cookies. Ingredients include flour, butter, sugar, and special ingredients (e.g., Chocolate Chip, Almond). There are two types of special cookies; a butter cookie is made up of flour, butter, and sugar; a super cookie is made up of butter cookie and a special ingredient.

When Pacman eats a butter cookie, she achieves 1 minute immunity from being consumed by a Ghost. When Pacman eats a super cookie, it takes a time lag of 30 seconds before she achieves 3 minutes of ghost-devouring power (30 seconds is for the Ghost to run or devour the Pacman).

Fig. 2.10 Sequence of pictures showing the collection of an ingredient

In the game, real Bluetooth-embedded objects are placed in different parts of the game area. In Fig. 2.10, a sequence of pictures shows a Pacman collecting an ingredient. When the Pacman is within range of the Bluetooth object (about a distance of 10 meters), communication takes place between the wearable computer and the Bluetooth device. The wearable computer sends the unique address of the Bluetooth device to the server, upon receiving it, the server will then decide if the player is eligible to collect the virtual ingredient that is associated with the physical Bluetooth object. If the player is not eligible (for example, she has already collected the ingredient), she will not be alerted to the object. Otherwise, an alert message will be shown on the player's HMD display.

The player has to hunt for the Bluetooth embedded object upon receiving the alert message in the surrounding physical area and thus adding elements of fun and adventure to the game play. Having found the object, collection is done simply by physically holding the object in her hands. This is achieved by the use of charge transfer sensing on the object that detects the player's touch. We have designed this capacitive sensor using QT161 IC chip from Quantum Research Group [28]. Once haptic data is collected by the sensor, the Bluetooth device embedded on the object will send an alert message to the wearable computer, which will in turn be relayed to the server. The server performs legitimacy check on the player's action, and then proceeds to updating its database as well as informing the wearable computer. The collection of ingredient exemplifies a natural tangible interaction that is involved through physically interacting with this object by human touch. Pacman is able to hold a real object naturally in hand as it should be in real-life treasure finding. Such a tangible action provides the player a sense of touch to the fantasy domain of game-play. The collection of the ingredient will be kept in a virtual inventory list and be immediately reflected in the display; moreover, the action occurs in real-time in the virtual world. As seen in the figure, collection is shown as an addition of an icon of a sugar jar to the inventory list after the ingredient has been collected. Pacman need not lug the physical object with her as she has collected the ingredient virtually.

Collaboration Between Players There is an essential element of collaboration in the game play between a Pacman/Ghost with her Helper, and between any allied Pacmen.

(i) Pacman/Ghost and Helper Collaboration Helper is in a good position to assist her partner as she has a complete view of Pac-world all the time, including the positions of all players and ingredients. Mobile players can only see the complete Pac-world under the VR mode. However, the AR mode is more advantageous for mobility because under VR mode movement is restricted since she does not have a view of the real world. Furthermore, as Helpers within the same team are physically close, they are able to collaborate between themselves and work out a strategy to achieve the team's goal. The advantage of this setup is that social interaction and collaboration is significant between Helpers, as well as between Helpers and their partners.

(ii) Pacman/Pacman Collaboration Pacman players can collaborate through transferring of ingredient between them, even if they are physically far from each other with the support of wireless LAN. For example, Pacman A can initiate a request for the list of unused ingredients Pacman B has. Upon approval, A can request a transfer of an ingredient from B, subject to approval by B. Transfer of an ingredient is important as Pacman may not be able to comb the whole game area for ingredients. She may lack some ingredients, which may have been collected by her ally. Strategy could be implemented, with the coordination from Helpers, to distribute ingredients between Pacmen. However, Pacmen are not allowed to transfer special cookies so as not to disadvantage the Ghosts.

Use of Special Cookie All special cookies can only be used once. When a Pacman consumes a special cookie, she will see an alert message on her HMD, informing her of the power she acquired. Furthermore, in real-time a label describing her acquired power will be placed on top of her Pacman avatar in the VR mode. This serves to inform all Helpers, including those from the Ghost team, of her ability. This is illustrated in Fig. 2.11.

Devouring Enemy Player To devour a Pacman, a Ghost must physically touch the Pacman's capacitive sensor pads on her shoulders as shown in Fig. 2.12. The

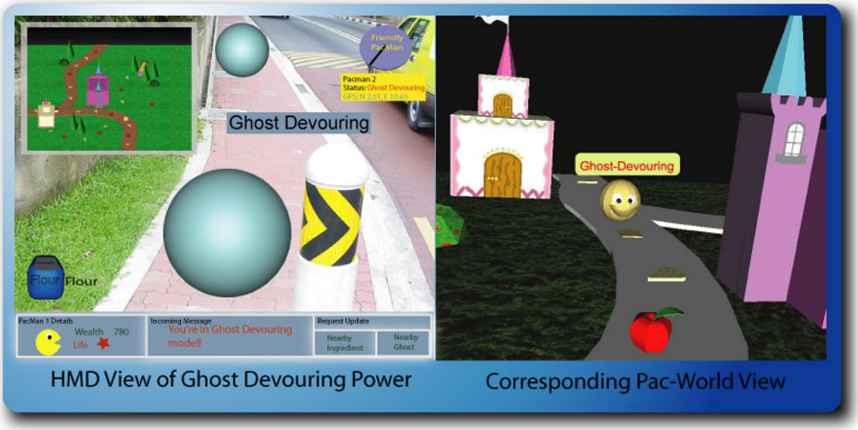

Fig. 2.11 HMD display and the corresponding VR mode view

same applies when a Pacman with Ghost-devouring capability devours a Ghost. When a Pacman is devoured, she loses one life point. Each Pacman is given two life points. The same applies to Ghosts. Devouring involves tangible physical touching contact between two players. As close proximity is involved, other forms of human interaction come into play. The act of devouring makes the game more tangible and fun, by involving more types of natural physical movement. As in when a Pacman player is the prey, her agility determines the "life-and-death" of her virtual Pacman role. Not only tangibility is brought to play in this fantasy world, but also other human perceptions and instincts. Thus this computer game provides the benefits of natural wide area free bodily movements as part of humanistic interaction between each person.

Ending the Game The game ends when either team meets its goal or when a time limit of 15 minutes has been reached.

2.4 User Study

To gain useful feedback from the end user, we conducted an experimental user-study survey on the Human Pacman system. Our aim was to find out from actual users their experience of the positive and negative aspects, interaction, and level of enjoyment in using the Human Pacman system. In these tests, the focus was placed on the different novel experiences offered by the game. Our study involved 23 subjects between the age of 21 and 33, of which eight were females and 15 were males. Amongst these people, 39% indicated their level of expertise in computers as advanced, 43% as intermediate, and the rest as beginner.

The experiment setup consisted of four parts. First, the subject was asked to play traditional arcade Pacman game on a desktop computer for five minutes. Then

Scene of Ghost catching PacMan

Fig. 2.12 Ghost catching a Pacman

a three minute Human Pacman video was shown to give him or her a better understanding of the game. This was followed by a 15 minutes trial where the subject tried the roles of Pacman, Ghost and Pacman's Helper for 5 minutes each, along with other subjects taking a different role. An expert user acted as the Ghost's Helper. Finally, the subject had to fill up a questionnaire and to provide comments on the system.

2.4.1 Questions and Aims

Table 2.2 (focussed on the role of real world players of Pacman and Ghost) and Table 2.3 (focussed on the role of Helper) show the list of questions that were asked in the survey. Following each question is the reason for asking this question in the user study.

Figures 2.13 and 2.14 give the user study results of all the multiple-choice questions. The options for each question and the percentage of users who chose each option are given in the figures.

2.4.2 Discussion

In this section, the response to the questions will be discussed. All the data had been analyzed using statistical methods.

Table 2.2 Questions of user study focussing on the real world play role of Pacman and Ghost

Question	Reason for asking
(i) How do you rank Human Pacman as compared with the normal Pacman game in terms of entertainment value? Please rate between 1 (normal Pacman more entertaining) to 7 (Human Pacman more entertaining)	As the idea of Human Pacman originates from the previous arcade Pacman, the fundamental concepts of game play are similar. The question aims to find out if any value has been added to the old Pacman game in the new system
(ii) How comfortable do you feel when using the Human Pacman system?	The wearable computer system is still rather bulky and heavy compared to mobile devices such as phones, Game Boys, and PDAs. We want to find out if and how much it affects the level of comfort of the user when the user dons it
(iii) How intuitive do you think it is to collect cookies by physically walking through them?	In everyday life, collection of an item is seldom, if ever, made by walking through it. We seek to understand if the user finds it intuitive to collect virtual cookies by walking through them just as is done in the original Pacman game
(iv) Please rate, from 1 (lowest) to 7 (highest), the level of excitement of playing as a Pacman in Pac-world (first person experience), in comparison with the arcade Pacman that you can play using a joystick/keyboard (third person experience)?	We want to find out if the immersive experience of Human Pacman makes the game more exciting. Arcade Pacman is used as the baseline for comparison as it is fundamentally similar in game-play
(v) What do you think of displaying "cookies" as virtual objects augmented inside the real world?	From this question, we want to find out how realistic the experience of collecting virtual cookies using AR is
(vi) Does the physical collection of real objects (special cookies) enhance the gaming experiences?	The collection of special cookies is a tangible interaction with a physical object that translates into a digital meaning (i.e., update of Pacman's inventory list). We want to find out if such graspable interaction enhances the game for the user
(vii) What do you think of the "capturing" event implemented in our system (touching the Pacman by Ghost)?	The "capturing" event is a reflection of the naturalistic and physical approach Human Pacman took towards tangible interaction. We seek to find out if the user enjoyed this feature
(viii) Do you like to play the Human Pacman game?	Having reflected on the game by answering the previous questions, the user is quizzed on the overall level of interest she has on Human Pacman

Table 2.2 (continued)

Question	Reason for asking
(ix) Please rate, from 1 (lowest) to 7 (highest), the feeling of "social interaction" in being a Ghost, Pacman, or Helper	We want to find out the level of social interaction experienced by the user in each role
(x) How do you compare this game with other computer games?	As Human Pacman aims to extend and differ itself from conventional human–computer interface used in normal computer games, this question investigates how well Human Pacman achieved its aim
(xi) How do you compare Human Pacman with the traditional "Catch Me" game?	The question looks at how Human Pacman compares with simple, non-computer based games. Traditional "Catch Me" game is used as a basis for comparison due to its similarity with the "capturing" event in Human Pacman. We want to see if adding the fantasy element has any benefit in the user's enjoyment over a normal catch game
(xii) If there is such a game in an amusement park, how much are you willing to pay to play the game?	Currently acquiring the whole Human Pacman system requires high overhead. So a commercially viable version of the system could only be sustained based on a pay-per-use basis, which is a norm in amusement parks. The question investigates the amount of revenue per person the system could bring in if implemented commercially. The question is asked to see if there is a link between such research systems and potential commercial use
(xiii) How often do you play computer games?	The question finds out how frequently the user plays computer games. This enables us to find out if her love for conventional computer games would influence her desire to play Human Pacman
(xiv) Please give us some comments on how we can improve the system and what the current drawbacks of the system are	We seek user's comments on our system to further improve the system in areas we may have neglected

First, we will discuss the set of results from the questions in Table 2.2 focussed on the real world players. Questions (i), (viii), (x), and (xi) examine how well Human Pacman is received by users; and how it compares with respect to other types of game in terms of user preference. As seen from the respective findings given in Fig. 2.13, most of the users are enthusiastic about Human Pacman. However, it is noted that, when compared with the traditional "Catch Me" game, 34.8% of the users gave a neutral stand in their preference. Results from (i) give an average rating of 5.85 (and a variance of 1.46) indicating that Human Pacman is much more favored than normal Pacman in terms of entertainment value. Statistical analysis with the T-test confirms the significance of our inference ($p = 6.72 \times 10^{-7}$).

The element of physicality may have been the pushing factor for the preference shown towards Human Pacman over arcade Pacman and conventional computer games. However, this is not so much of a benefit over the traditional "Catch Me"

Table 2.3 Questions in the user study focussing on the role of Helper

Questions	Reason for asking
(i) Does the VR mode give you a good idea about the game environment?	It is important for Helper to understand the situation her partner is in so as to dispense the appropriate advice. The ability to comprehend the game environment from the VR mode "Gods-view" is essential in helping her access the situation. Thus we wanted to see if this is confirmed in the user's opinion
(ii) Do you think Helper increases the chances of winning?	Helper is an additional feature to the original game. It is introduced to breach the geographical barrier in mixed reality gaming. However, we do not want to add this feature just for this sole purpose. We would like to find out if this enhancement to the game is useful
(iii) Does Helper make the game more enjoyable for Pacman/Ghost?	Helper is supposed to be an enhancement to the original game. Thus, if this new role does not make the game more enjoyable to the original players, there may be a need to reconsider the inclusion of Helper
(iv) How boring/exciting is the game for Helpers? Please rank from the 1 (very boring) to 7 (very exciting)	As the role of Helper is played by another person, we should find out from the point of view of Helper whether he or she is enjoying the game as well
(v) Currently the game is played by one Pacman/Ghost to a Helper. Do you think the game would be more interesting for the Helper if he/she could assist more Pacmen/Ghosts? If yes, what is the optimal number? If not, why?	Human Pacman basically revolves around social and physical interaction among all players. Generally, these interactions will increase with more players, thus making the game more enjoyable, too. However, as number of players increases, confusion will inevitably start to creep in. We would like to find out what is generally the optimal number of players
(vi) Do you think the frequency of conversation will increase when the complexity of the game (in terms of area size and number of Pacmen/Ghosts) is increased?	As Human Pacman is based on virtual and real interactions, we would like to know if complexity of the maze will affect the frequency of communication
(vii) Do you think Pacman needs a Helper?	The main role of Pacman helper is to guide Pacman to all the cookies and avoid the path of Ghost. However, some players may find it more exciting to be able to explore the real world freely and without any reins
(viii) Do you think Ghost needs a Helper?	The main role of Ghost is to track down Pacman. Similar to the above situation, some players may feel that the additional help is redundant and would like to explore the real world freely

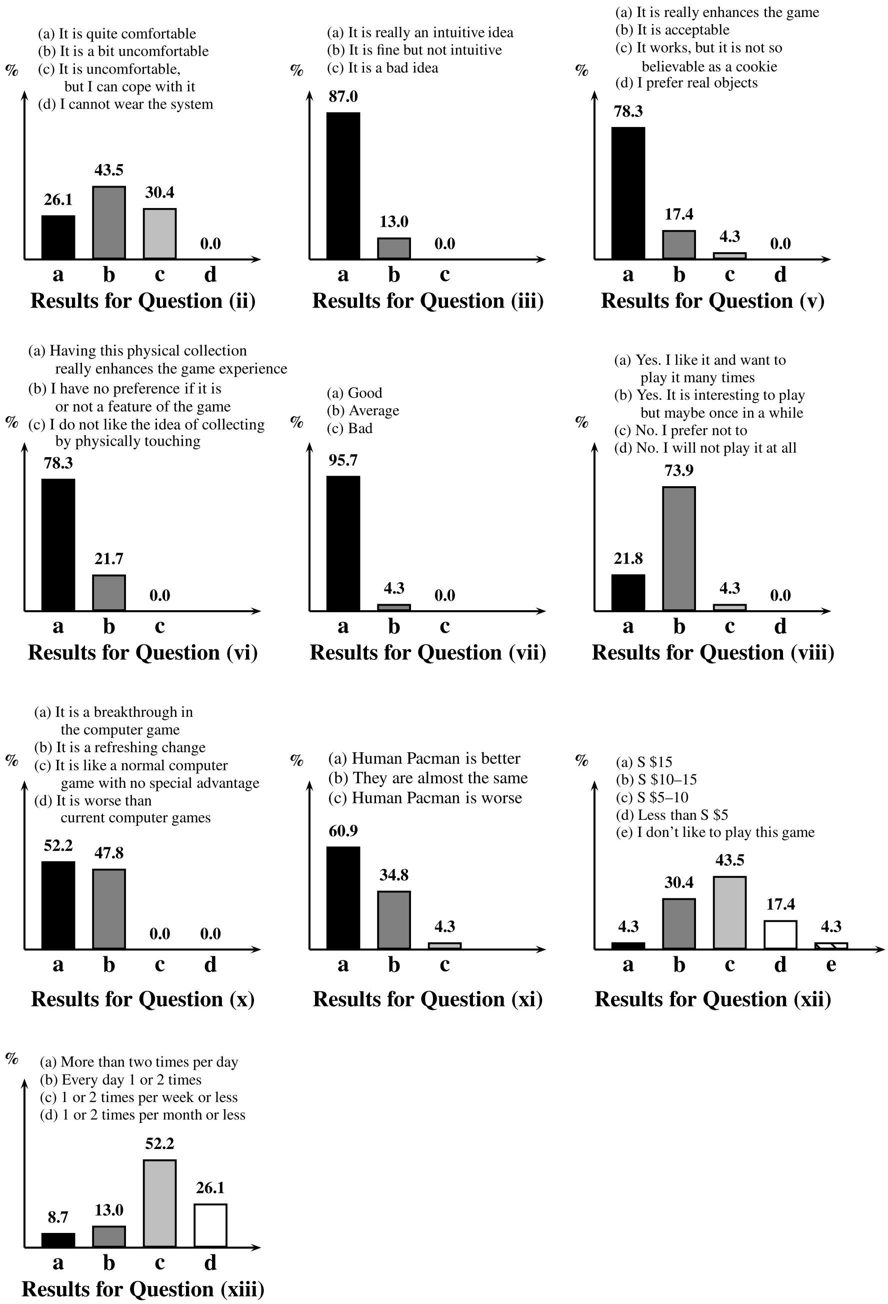

Fig. 2.13 Graph results for all multiple choice questions focussed on the real world players (some questions have no graphs and are described in the main text only)

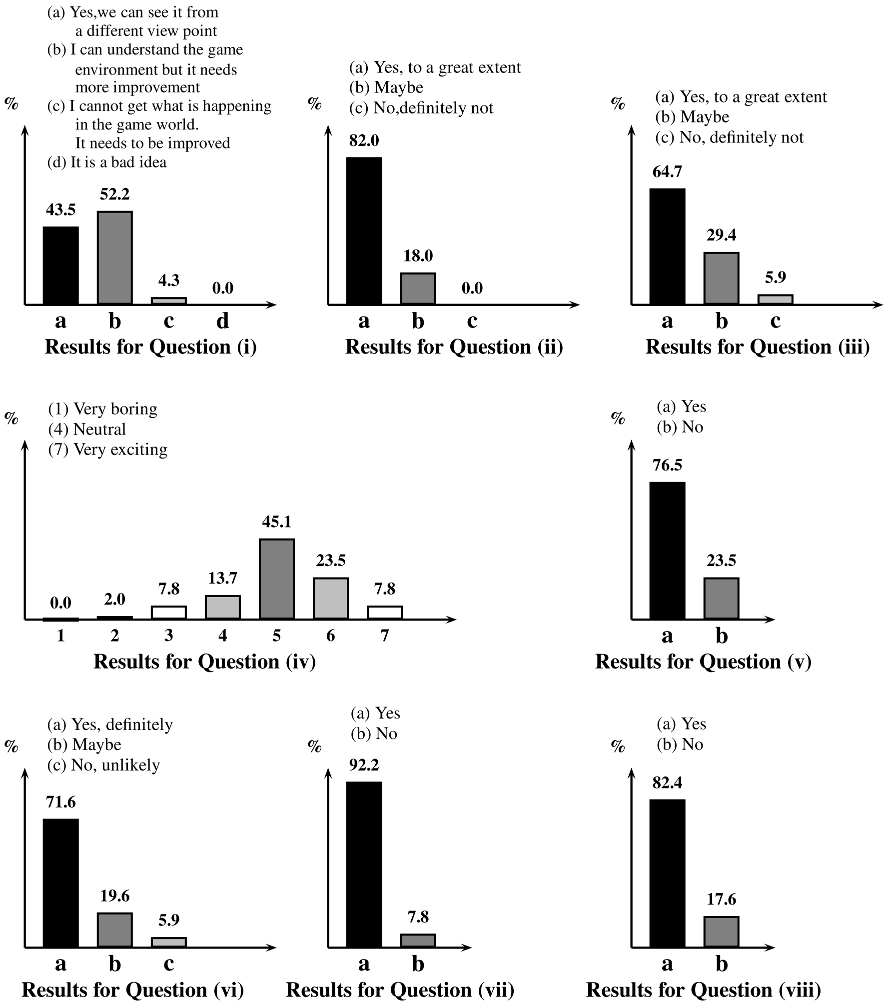

Fig. 2.14 Graph of the results for questions related to the virtual Helper players

game (which by itself is a game that involves a high level of physical participation). A number of users commented that they like the idea of "physical involvement" and "physical movement" in Human Pacman. Some said that such movement is a good form of exercise. Note that 60.9% of the users still prefer Human Pacman over the "Catch Me" game. This indicates that the element of physical involvement in Human Pacman is not its sole attraction. The immersive experience in the role playing of Pacman could be another element that users enjoyed over arcade Pacman and conventional computer games. Findings from Question (iv) give the average level of excitement rated by the subjects as 6.0 (and a variance of 0.182) for the first person experience in Pac-world and 3.33 (variance of 0.97) for the third person experience in arcade Pacman, indicating a higher level of excitement in the former. The non-parametric two conditions Wilcoxon statistical test confirms the significant difference in the feeling of excitement by the players at the level of $p = 4.88 \times 10^{-4}$.

As reflected by many users, the backpack holding the wearable computer system is bulky and heavy, and the HMD is cumbersome to wear. As seen from the results obtained for Question (ii), 73.9% of the users found the wearable computer to be uncomfortable. This could be the deterring factor for 77% of those who indicated that they like to play Human Pacman but would refrain from playing it frequently. The absence of equipment weighing down the user could also make traditional "Catch Me" game more attractive as one is unencumbered physically.

Despite not being a normal day-to-day experience, collecting virtual cookies by walking through them is deemed to be intuitive by 87% of the users (as seen in Fig. 2.13(iii)). The rest found the experience to be acceptable, though not intuitive. Findings for Question (v) show that 78.3% found that the use of virtual cookies enhances the game, whereas 17.4% feel that the cookies are acceptable as virtual objects but they fail to enhance the game.

A shift in alignment of virtual cookies from their supposed absolute position in the real space (caused by sensing drifts), mentioned by some users, could be the reason why virtual cookies to some users seem lacking realism, and thus being unable to enhance the game. As the view of virtual cookies is calculated with respect to the user's location, any discrepancies of her exact position may lead to the "shifting" of the absolute position of the virtual cookies in the real space. Since the system uses DRM-III and the dead-reckoning method to estimate displacement of the user, an inaccurate estimation of her stride (which varies with individual) or the wrong count for the number of steps taken will introduce error in the estimate. The location of the user thus computed is an estimate and may not reflect her true position in the physical space. Some users have reflected that the DRM-III module failed to sense all the footsteps taken by the user.

Users also found the visual cue of the cookies collection (i.e., cookies disappearing from AR world when collected) to be weak and insufficient in providing a "better feel" of collection. A number of users suggested using sound, for example, a "beep", to indicate collection of each virtual cookie. A lack of realistic affordance of virtual cookies makes reliance on other cues more important to indicate collection.

On the issue of tangible interaction element in Human Pacman, 78.3% (as seen in Fig. 2.13(vi)) found that the graspable interaction offered by the collection of real objects enhances the game. The other 21.7% gave a neutral response towards having this collection as part of the game. Almost all the users indicated in Question (vii) that they like the "capturing" event. Despite being both naturalistic interaction with the physical world, users seemed to like the "capturing" event more. This suggests the physical human-to-human interaction in the process of "capturing" makes the event more enjoyable.

Results obtained for Question (ix) show that the feeling of having social interaction have rated means of 5.67, 5.41 and 4.17 with variances of 0.97, 1.17 and

0.88 while playing as Pacman, Ghost and Helper, respectively. The non-parametric Wilcoxon test shows insignificant difference in the level of social interaction between Pacman and Ghost ($p = 0.5$), while the difference of between being Ghost and Helper is significant with $p = 0.0039$. Helper role is perceived to have lesser social interaction as compared to the other roles. We feel this is related to further questions discussed below about Helper's role, and that the role is less enjoyable. As this is an entertainment system, the fact that Helper has more limited modes of interaction than the physical players seems to lead to less enjoyment and a feeling of social interaction.

Based on the results from Question (xii), the average amount the users are willing to spend to play Human Pacman in amusement parks is S $8.15 with a variance of 16.5. This is in the typical price range of amusement rides available locally. It is noted that the 17.4% who would pay less than S $5 to play Human Pacman also indicated in Question (xiii) that they seldom play computer games. Perhaps they do not enjoy playing games as much as the average person, and are therefore less willing to spend on it.

We now discuss the results from the questions focussed on the experience of the virtual Helper player in Table 2.3.

As reflected by the response to Question (i), almost all users were able to comprehend the game environment from the VR mode. It is noted in the feedback comments that more than half of the users felt that more improvement still needs to be made for the VR mode. Users would like to see better 3D graphics and more variety of virtual objects in the VR world. Perhaps the lack of visually appealing 3D interface as compared to those found in commercial computer games makes Helper's role less attractive (our 3D models are non-commercial and designed in the laboratory by students).

The subsequent three questions (Questions (ii), (iii) and (iv)) focus on the experience of Helper in the game. Nearly 4 in every 5 participants' responses to Question (ii) agreed on the fact that Helper increases the chances of winning, while the rest thought maybe, and none disagreed on the role of Helper in winning the game. From Question (iii), a lesser 64.7% reflected that the role of Helper made the game more enjoyable for Pacman and Ghost, and 5.9% felt otherwise. The remaining 29.4% hesitated and thought it probably did so. Question (iv) sought to examine from the perspective of users who played as Helpers on how enjoyable they felt toward the role. Using a scale of 1 (very boring) to 7 (very exciting), a mean rating of 4.96 with a variance of 1.93 was obtained. Evidently, these numbers illustrate the fact that while Helpers are definitely beneficial to the game, the issue of fun and thrill has not been addressed well, since the user (Helper role) did not enjoy it as much as they understood its strategic importance. This may be due to the fact that Helper's interactions are limited only to text-based messaging. To improve this, perhaps Helper could be assigned to more interesting tasks. For example, Helpers could be granted abilities to temporary make the virtual cookies invisible to the enemies or to make their assisted player immune from being captured, as was suggested by some users.

Question (v) explores the other possibilities and options to be expanded on the interactions between the real physical and virtual online players. More than twothirds of the users revealed that the game will be more interesting if a Helper can assist more than one Pacman or Ghost at the same time, so that they can collaborate and form strategies to win the game. According to the feedback, the average optimal number of Pacman or Ghost per Helper is three, as most users commented that it would be too confusing if there were too many players involved.

Regarding the issue of interaction in terms of textual conversation versus complexity of the game, we found out from Question (vi) that 70.6% felt that the communication will definitely be more active as the complexity of the game is increased in terms of the area size and the number of players. It can be hypothesized that when more physical players are introduced, Helpers have to put in more effort to coordinate the players who are roaming in the real world. The physical players would also need more information too if the game area becomes wider and harder to explore physically.

A correlation test was done on those who answered Question (iii) and Question (v) to find out the relationship between users who enjoy (and those who do not) the game and their attitudes toward the issue of higher communication with increasing the complexity of the game. A high degree of correlation coefficient of 0.876 was derived. This suggests that those who enjoyed the game initially would most likely choose to participate and contribute actively to their teammates when the complexity of the game is increased. On the other hand, the remaining who did not find the game interesting in the first place (Question (iii)) do not feel communication would increase with increasing complexity (Question (v)). In other words, it could be hypothesized from these results that a higher enjoyment can promote a positive increase in communicative interactions.

The two remaining questions (Questions (vii) and (viii)) seek conclusions from the users' point of view on the necessity of Helper's role for both Pacman and Ghost. Surprisingly, the results vary slightly instead of being close to each other: 92.3% believed that Pacman needs a Helper, while slightly fewer 82.4% thought Ghosts required such support. While majority agreed on the essential existence of Helpers, a small group commented that it might be better to let the physical players explore on their own as there could be more fun in self exploration, especially for Ghost whose sole job is simply to eliminate Pacman. Nonetheless, the fact that a large majority agreed on the necessity of Helper indicated that it is not something added for the sake of adding; it serves a purpose in completing the whole framework of the game.

2.4.3 Analysis of Message Logs

In this section, we will analyze some excerpts from the text messages that contain the conversation which was logged during the user study. Some interesting and unexpected results have been obtained and should be useful to in order to gain more knowledge in the context of real-to-virtual interaction which we are studying here.

One significant result from the user study is illustrated by the fact that the players often assumed beforehand what their team member would like to know or ask. A typical message log often looks like this:

Pacman's Helper: Carry on.
Pacman's Helper: Go right.
Pacman's Helper: Go straight.
Pacman's Helper: Left.
Pacman's Helper: Go left!!!
Pacman's Helper: Run!!!

Here Pacman remained silent and her Helper dominated the conversation. As a matter of fact, Pacman was preoccupied with her physical activities of moving and searching that she could find no time to reply. Moreover, probably all that she needed (and did not need) to know was already answered by her Helper. The conversation had, in fact, turned into a monologue and interaction has lost its meaning here.

However, for users who are more proactive, we can still observe some two-way traffic of interactions taking place even in trivial cases of guiding the way:

Pacman: What do you mean?
Pacman's Helper: Try going backwards.
Pacman's Helper: Stop!
Pacman: What's next?
Pacman's Helper: Turn right!

Therefore, despite the same settings, we recognize that the degree of interactions that take place might vary for different individuals. Encouraging the players to collaborate in reaching the common goal is essential to promote more interactions.

The importance of collaborations often becomes obvious in the face of difficult problems that arise during critical moments, for instance, toward the near end of the game. The role of Helpers in the following scenarios contributes significantly to the eventual outcome:

Pacman: Where's the last cookie?
Pacman's Helper: I suggest you try killing Ghost first.
Pacman: Why?
Pacman's Helper: Coz he is still guarding the last cookie!
Pacman: What shall I do!?

While the element of surprise seemed to be spoiled by having a Pacman's Helper informing Pacman what has actually happened, it in fact did not spoil the game or caused a stalemate. The next scenario followed from the previous scenario, and Ghost decided on a strategy after she obtained the information from Helper.

Ghost's Helper: 1 cookie left for Pacman.
Ghost: This one??
Ghost: Tell me when he's coming.
Ghost: I'm gonna camp here.
Ghost's Helper: Incoming! But- she's a Super Pacman now!

Through Helpers on both sides, each had devised its own strategy. Ghost, after being informed by her Helper that only one last cookie remains for Pacman, decided that it would be a wise idea to lay ambush near the cookie. Upon learning that Ghost is idling around the last cookie, Pacman's Helper passed this information to Pacman. To outwit Ghost, Pacman found the Super Cookie with the aid of Helper, and became a Super Pacman. Subsequently she eliminated Ghost by surprise, finished collecting the last cookie and won the game.

Pacman's Helper: Cool, we won!
Pacman: Yeah, cool stuff, great job!
Pacman's Helper: Same to you.

Through simple text messaging, ideas and emotions are channeled mutually between real physical and virtual online players, resulting in a unique interplay of social behaviors across different platforms.

2.4.4 Summary Findings

Through the user study survey, we evaluated how the Human Pacman system model fits into the interaction theme we started out with. We believe that from the findings we can say that users like the idea of Human Pacman as a whole. This is seen from their attitude towards playing the game, their willingness to pay to play the game, and their preference of Human Pacman over other types of games. It is promising that users were positive about the physical interaction aspects of the game such as the first person point of view and the tangible interactive elements. However, it is clear that improvements should be made to reduce the size and weight of the wearable computer.

On the individual elements of Human Pacman, the collection of virtual cookies is well accepted though improvements can be made to make the whole experience of moving towards virtual cookies and collecting them more realistic. Sound could be added as a cue to the collection. More accurate and precise tracking device could also be developed to minimize error in location tracking, which was a factor of disapproval from the users.

Though both the "capturing" event and collection of physical objects in the game add value to the game, it is found that the former is better liked. This could be because during the "capturing" of Pacman, physical human-to-human interaction is involved, along with other forms of human interaction that comes into play (e.g., shrieking). The study also shows that immersive experience is valued by users. Users like to be "physically involved" in this first-person gaming experience. This positive reception is important to note, as the tangible and physical aspects introduced into Human Pacman are some of its major strengths.

Nonetheless, the mean rating of 4.96 out of 7 received for the Helper role in terms of enjoyment level indicated that perhaps more features should be added to enhance the role. Interaction in the form of text messaging alone may not be sufficient to encourage Helpers to stay engaged or maintain their level of interest. Consequently, some users reflected that even if the overall game complexity is increased, the level of interaction might not increase proportionally. This would mainly be due to the fact that they will still be primarily guiding the physical players through text messaging. Besides, some might have rejected the game as boring in the first place, no matter what the complexity.

We also found that interactions might always not take place readily as what the designers had intended in the early stage, whereby the game was actually customized to promote two-way communication between the physical players and the virtual online players. However, the a priori knowledge of users on their partner's requirement often led to pre-assumptions, which in turn led to one-way communication – Helper giving commands on where to go, while Pacman/Helper just following the instructions. Nonetheless, as the users approach critical stages (collecting the final cookie or capturing the Pacman) collaborations become inevitable as the users interact with each other to achieve their ultimate goal of winning the game.

Based on the user study, we did a qualitative analysis on users' perceptions toward the different form of interactions and produced a color interactive matrix as shown in Fig. 2.15. We assigned different levels of importance, in terms of high, medium and low, to each interaction. The levels of importance are obtained based on the user study results of the general effectiveness (useful, intuitive, enjoyable) of each form of interaction. Evidently, Pacman experiences most of the important interactions compared to other users, as the game design is initially revolved around the Pacman character to a larger extent. Interactions between users of any roles are also higher than to those between users and objects, implying the importance of social interactions in mixed reality gaming environment.

2.5 Mobile Service and Ubicomp Issues

In recent years, we have witnessed phenomenal growth of mobile devices. Together with current trends in embedded systems and software, real-time interaction and omnipresent wireless networking, these devices fertilize the formation of a ubicomp landscape, in which digital environments are aware of the presence of users, and communicate with the user via natural interaction means. Human Pacman attempts to incorporate a number of mobile and ubicomp elements into the game play, for instance, mobility, ubiquity, awareness, intelligence, and natural interaction. In this section, we will examine the various repercussions in the system by studying the three principle features of mobile computing: wireless communication, mobility and

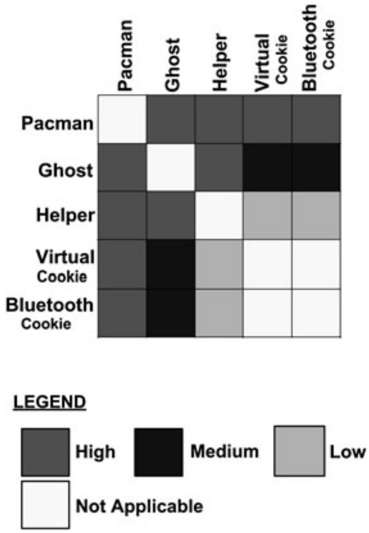

Fig. 2.15 Interactive matrix

portability [13]; following which we will examine two of the interaction themes in ubicomp, that is, tangible interfaces and context-awareness in the context of Human Pacman.

2.5.1 Mobile Computing

From a broader perspective, the game of Human Pacman is a type of user adaptive application that is built upon the infrastructure of wearable and mobile computing, as well as the wireless multimedia communication. It aims to utilize the mentioned technology to provide nomadic players with personalized location based entertainment. However, there are numerous problems associated with the actualization of these concepts.

2.5.1.1 Wireless Communication

We have identified three main problems in deploying the wireless communication network, in this case, the wireless LAN of IEEE 802.11b. Firstly, disconnections in communication often interrupt the flow of the game. Secondly, limitation in bandwidth sets constraints on the type of multimedia data that can be sent between players and between the players and the server. For example, we have to limit ourselves to simple text files for the frequent location, perspective, and status updates between the player's wearable computer and the server; and forego with the initial intention of sending live video streams between players. Thirdly, unstable outdoor conditions often result in high error rate of the network. These three factors, in turn, increase communication latency which is due to retransmission, retransmission on time-out delays, error control processing, and short disconnections. Therefore, it is rather difficult to maintain Quality of Service (QoS), especially when players accidentally move beyond the coverage of the network, or move into areas of high interference. We try to minimize the problems by carefully selecting the area for game play in the vicinity of the University campus in Singapore where network connectivity is good. Also, when designing the software for the game, we have embedded components that enable continual processing based on local data on the wearable computer so that when short disconnections occur, the game can still proceed without many disruptions. Lastly, the client/server communication between the server and wearable computers occurs in an asynchronous manner in order to reduce the problem of latency.

2.5.1.2 Mobility

The combination of networking and mobility engender this new form of entertainment system where support for collaborative environment for impromptu communication between mobile players is essential. The dynamism of data, including location and context information from trackers and sensors, contributes much to the volatility of data in the whole system. This creates a grave problem when the wearable computer is dozing because of inactivity of players or power failure. Also, with the players moving around in an outdoor physical area in this type of wide area mobile gaming, they might move across multiple heterogeneous wireless networks and therefore suffer from address migration interruption between the networks. However, in Human Pacman, we try to avoid these difficulties by limiting the size of the game play area and using single centralized server network architecture.

2.5.1.3 Portability

Wireless networking with mobile computing has greatly enhanced the utility of carrying a computing device, in this case, a wearable computer. However, unencumbered portability is very important for the enjoyability of the game. Conventional portable computing devices like netbooks and handphones often suffer from the lack of raw processing power and storage size when running multimedia entertainment programs. With the use of custom-built wearable computer, we managed to secure high computing power together with large storage volume for our application (for details on wearable computer, please, see the previous section on system design). Another important portability issue is the power for the computing device. Since Human Pacman is a game with short duration of play (recommended 10 minutes), the wearable computer that is powered by two Sony InfoLithium batteries lasting about three hours can adequately manage the task. The last issue in portability is the user interface. Duchamp and Feiner have investigated the use of head-mounted virtual reality displays for portable computers [10]. They concluded with several disadvantages of using the display, including the hassle of the head gear, low-resolution, eye fatigue, and the requirement for dim lighting conditions. These problems also exist in Human Pacman since we are also using head mounted display for Augmented Reality outdoor gaming. Nevertheless, as mentioned previously, due to the short duration of play in Human Pacman, the problem is bearable to the players.

2.5.2 Ubicomp

Ubicomp, also known as "Ubiquitous Computing", is a phrase which late Mark Weiser (1952–1999) described in 1988 as "calm technology that recedes into the background of our lives". Though not strictly making computers available throughout the physical environment but invisible to the user as described by Weiser [37], Human Pacman envisions applying the same concept of calm technology into computer gaming by experimenting with tangible interfaces and context-awareness entertainment and communication, which are, in fact, two of the interaction themes in ubicomp. Tangible interfaces and context-awareness, which are integral components in the game play of Human Pacman, are discussed in the following subsections. Since the game is played in a wide outdoor area, context-awareness issues are studied with the focus on outdoor settings.

2.5.2.1 Tangible Interface

Even though Graphical User Interface (GUI) has been and still is the dominant paradigm for interactions with computers, we are increasingly encountering computation that moves beyond the traditional confines of the desk and attempts to incorporate itself more richly into our daily experience of the physical and social world. Work on physical interaction started to appear in the literature in the early 1990s with the introduction of Computer-Augmented Environments [8] that have envisioned the merging of electronic systems into the physical world instead of attempting to replace them as in virtual reality environments.

Over the years, a number of projects have explored this new paradigm of interaction termed tangible computing. Early attempts include Bishop's Marble Answering Machine [32] that has made a compelling demonstration of passive marbles as "containers" for voice messages; "Brick" by [12] that is essentially a new input device that can be tightly coupled to virtual objects for manipulation or for expressing action (e.g., to set parameters or for initiating processes); "Tangible Bits" and "mediaBlocks" from MIT media lab [15] that allow users to "grasp & manipulate" bits in the center of their attention by coupling the bits with everyday physical objects and architectural surfaces, and "contain, transport & manipulate" online media using small, electronically tagged wooden blocks that serve as physical icons ("phicons"), respectively. Nevertheless, in all of these implementations of tangible computing, computer interaction remains passive with human, initiating communication with the tangible objects, and confined only between virtual objects and humans.

However, in Human Pacman, with the use of embedded Bluetooth devices and capacitive sensors, we explore active communication between computers and human players instantiated by Bluetooth devices, as well as graspable interaction between humans and computers, and between human players themselves. Therefore, there are two distinctive manifestations of tangible interfaces in Human Pacman; the first is being implemented in 'Special Ingredient', which is actually a Bluetooth embedded object with capacitive sensor, and the second is the capacitive sensor shoulder pads on the wearable computers for Pacmen and Ghosts.

Bluetooth is incorporated into the system where there is already wireless LAN support for communication because firstly it provides paired communication with security which is essential for one-to-one communication between the 'Ingredient' and the player; secondly, Bluetooth devices support automatic device discovery and connection setup when they are within range, therefore providing the backbone for reasoning by close physical proximity in the game play. This allows Pacman to search nearby area for 'Ingredient' once being alerted of the presence of Bluetooth embedded device. On the other hand, tangible interaction between the Bluetooth embedded object and the player is made possible by using a capacitive sensor for detecting the action of touch by the player. In this way, we harness the physical and tactile abilities of Pacmen to support the computational task of registering the discovery and collection of virtual ingredient. Another important aspect of this design is the clever exploitation of the affordances of the object's physical properties whereby without prior training, players can intuitively associate the action of picking up the 'Ingredient' object with the collection of it in their virtual inventory as well as having the action simultaneously occur in the virtual world.

The use of capacitive sensor shoulder pads of wearable computer for the detection of 'Devouring' action in game play serves the purpose of demonstrating how computation can be used in concert with naturalistic activities, in this case, the action of physically catching the enemy on the shoulder. Also, by making the distinction between "interface" and "action" very much reduced, i.e., physical action of tapping versus a mouse-click for interaction, Human Pacman allows the players to experience transparent interchange between human and computer in computer gaming.

2.5.2.2 Context Awareness in Outdoor Environment

Researchers at Olivetti Research Ltd. (ORL) and Xerox PARC Laboratory pioneered the context-aware computing area with the introduction of Active Badge System and PARCTab [30, 35]. However, these systems were expensive with the extensive use of infrared transceivers, and were limited in scope as their applications were confined to an indoor room. With the introduction of GPS and emergence of cheap but accurate sensors, a number of context-aware systems for outdoor applications were built.

One notable system was the Georgia Tech Cyberguide project [17] where mobile context-aware tour guide prototypes were made to provide information to a tourist based on her position and orientation. Similarly, at the University of Canterbury, some context-aware fieldwork tools have been developed: an archeological assistant tool [29], a giraffe observation tool [27], and a rhino identification tool [26] to enable the users to make location dependent notes using a PalmPilot as terminal and GPS for positioning. Unlike Human Pacman that uses Augmented reality techniques as its main computer–human interface, these systems have only primitive 2D maps and text presented on palmtops.

Another tourist assistant called Smart Sight was developed at the Carnegie Mellon University [38], which was able to translate from and to local language, handle queries posed and answer in spoken language, and aid navigational around the campus with the use of wearable computers. Nevertheless, since laptops were used as part of the mobile computer system, their sheer weight and bulkiness have greatly reduced user's mobility and comfort of use. In Human Pacman, players are provided with custom-built wearable computers that are designed, built, and developed in our lab especially for this application.

The use of GPS and outdoor physical area for computer gaming is pioneered by ARQuake [34] as mentioned in the 'Background' section. This game is an AR extension of the original desktop Quake game of player shooting virtual monster (in this case, the monsters are presented in physical world using AR techniques) in first person perspective.

There are three different ways in which the idea of context awareness is being applied to in Human Pacman. Firstly, with the use of GPS and DRM to provide various data required for tracking the players in wide area outdoor environment, location awareness of the system is made possible. Despite being the most widely publicized and applied location-sensing system, GPS suffers from accuracy and selective availability. The problems are compensated through sensorfusion with DRM. In Human Pacman, we are taking advantage of user's mobility in the wide outdoor area to adapt the system's behavior based on her current location. This location context is being made use of throughout the game play for augmented reality (AR) placing of virtual cookies, as well as calculating the relative positions of allied players.

Another important component in realizing AR elements in Human Pacman is the inertia sensor. Through data collected from it, the system is aware of current perspective of the player and thereby displays virtual objects accordingly. Besides, Human Pacman also experiments with information context in human–computer interface with the Helper player having information access to other players via wireless LAN and providing them with necessary and timely information.

2.5.3 Addressing Sensor-Tracking Issues

In Human Pacman, we tried to combine materials from cognitive psychology and sociology with that from computer science. However, the vast number of issues encountered have exceeded the scope of this paper. Therefore, we will concentrate on

Table 2.4 Five questions and answers posing human–computer communication challenges for interaction design in the case of Human Pacman

Basic question	Human Pacman interface answers
Address. How do I address one (or more) of many possible devices?	With the implementation of Ubiquitous Computing, the system constitutes a more amorphous concept with automated interactions between sensors and the computer. The existence of a unique address for each Bluetooth device disambiguates the Bluetooth embedded objects. Furthermore, centralized control of the server prevents ambiguity of intended target system even when there is more than one player near the Bluetooth device. Keyboard and mouse are used for messaging and selection of the 'Ingredients' to be exchanged between Pacmen
Attention. How do I know the system is ready and attending to my actions?	Graphical feedback is used extensively from providing alert message in popped up window, to refreshing virtual inventory after Pacman has picked up Bluetooth embedded object. Also, since this graphical information is provided in the HMD directly in the zone of the user's attention, such objects are highly effective
Action. How do I effect a meaningful action, control its extent and possibly specify a target or targets for my action?	The Pacman/Ghost click on preset messages to be sent to Helpers. Pacmen click on graphical representation of 'Ingredient' to be exchanged. Clearly labeled Bluetooth embedded objects are to be found in the physical space where interaction is intuitive. According to Norman's Theory of Action [23], this form of tangible interface bridges the 'Gulf of Execution'
Alignment. How do I know the system is doing (has done) the right thing?	Real time graphical feedback presents distinctive and timely graphical elements establishing the context of the system
Accident. How do I avoid mistakes?	Pacman right-clicks on virtual ingredient in order to dump the ingredient

discussing sensor-tracking issues with respect to human–computer interface design. According to Bellotti [1], there are five questions posing human–computer communication challenges for interaction design. In Table 2.4, we summarize the sensing approaches to interaction in Human Pacman with respect to the five questions raised.

2.6 Conclusion

The continual propagation of digital communication and entertainment in recent years forces many changes in societal psyche and lifestyle, i.e., how we think, work and play. With physical and mobile gaming gaining popularity, traditional paradigms of entertainment will irrevocably shake from the stale television-set inertia. We believe that Human Pacman heralds the conjuration and growth of a new genre of computer game that is built on mobility, physical actions and the real world as a playground. Reality, in this case, is becoming more exotic than fantasy because of the mixed reality element in the game play. On the other hand, emphasis on physical actions might even bring forth the evolvement of professional physical gaming as competitive sport of the future, for example, 'PacMan International League'.

The element of social gaming in Human PacMan symbolizes the nascence of humanity in future digital entertainment. People are looking forward to widening their circle of friends and colleagues through social collaboration in game play. A new form of interactive entertainment is evolved.

Another important area of impact is the field of education. The technology presented in Human PacMan can be exported to applications in educational training that stresses on "learn by experience". Students are immersed in a real site of action, and are given instructions visually through head mounted display or verbally through speaker/earphone. This technology serves as a powerful instrument of cognition since it can enhance both experimenting and reflective thoughts through mixed reality and interactive experience.

In conclusion, we believe Human PacMan is a pioneer in the new hybrid of physical, social, and mobile gaming that is built on ubiquitous computing and networking technology. The players are able to experience seamless transition between the real and virtual world, and therefore a higher than ever level of sensory gratification is obtained.

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Chapter 3
Interactive Theater Experience with 3D Live Captured Actors and Spatial Sound

3.1 Introduction

Digital technology has given rise to new media forms. Interactive theater is such a new type of media that introduces new digital interaction methods into theater. In a typical experience of interactive theaters, people enter cyberspace and enjoy the development of a story in a nonlinear manner by interacting with characters in the story. Therefore, in contrast to conventional theater which presents predetermined scenes and story settings unilaterally, interactive theater makes it possible for the viewer to actually take part in the plays and enjoy a first person experience.

In this chapter, we are concerned with embodied mixed reality techniques using video-see-through HMDs (head mounted displays). Our research goal is to explore the potential of embodied mixed reality space as an interactive theater experience medium. What makes our system advantageous is that for the first time we combine embodied mixed reality, live 3D human actor capture, and ambient intelligence, for an increased sense of presence and interaction.

We present here an Interactive Theater System using Mixed Reality, 3D Live, spatial sound and Ambient Intelligence. In this system, thanks to embodied mixed reality and ambient intelligence, audiences are totally submerged into an imaginative virtual world of the play in 3D form. They can walk around to view the show at any view point, to see different parts and locations of the story scene, and to follow the story according to their own interests.

Moreover, with 3D Live technology which allows live 3D human capture, our Interactive Theater System enables actors at different places all around the world play together at the same place in real time. Audiences can see the performance of these actors/actresses as if they were really in front of them.

Furthermore, using Mixed Reality technologies, audiences can see both virtual objects and the real world as the same time. Thus, they can see not only actors/actresses of the play but the other audiences as well. All of them can also interact and participate in the play to change the episode, which will provide very special experience.

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Our system of Mixed Reality and 3D Live is intended to bring performance art to people while offering to the performance artists a creative tool to extend the grammar of the traditional theater. This interactive theater also enables social networking and relations, which is the essence of the theater, by supporting simultaneous participants in human-to-human social manner.

3.2 Previous Work on Interactive Theater

The systematic study of the expressive resources of the body started in France with Francois Delsarte at the end of the 1800s [3, 5]. Delsarte studied how people gestured in real life and elaborated a lexicon of gestures, each of which, was supposed to have a direct correlation with the psychological state of man. Delsarte claimed that for every emotion, of whatever kind, there is a corresponding body movement. He also believed that a perfect reproduction of the outer manifestation of some passion will induce, by reflex, that same passion. Delsarte inspired us to have a lexicon of gestures as working material to start from. By providing automatic and unencumbering gesture recognition, technology offers a tool to study and rehearse theater. It also provides us with tools which augment the actor's action with synchronized digital multimedia presentations.

Delsarte's "laws of expression" spread widely in Europe, Russia, and the United States. At the beginning of the century, Vsevolod Meyerhold at the Moscow Art Theater developed a theatrical approach which moved away from the naturalism of Stanislavski. Meyerhold looked to the techniques of the Commedia dell'Arte, pantomime, the circus, and to the Kabuki and Noh theaters of Japan for inspiration, and created a technique of the actor which he called "Biomechanics." Meyerhold was fascinated by movement, and trained actors to be acrobats, clowns, dancers, singers, and jugglers, capable of rapid transitions from one role to another. He banished virtuosity in scene and costume decoration and focused on the actor's body and his gestural skills to convey the emotions of the moment. By presenting to the public properly executed physical actions and by drawing upon their complicity of imagination, Meyerhold aimed at a theater in which spectators would be invited to social and political insights by the strength of the emotional communication of gesture. Meyerhold's work stimulated us to investigate the relationship between motion and emotion.

Later in the century, Bertold Brecht elaborated a theory of acting and staging aimed at jolting the audience out of its uncritical stupor. Performers of his plays used physical gestures to illuminate the characters they played, and maintained a distance between the part and themselves. The search of an ideal gesture which distills the essence of a moment (Gestus) is an essential part of his technique. Brecht wanted actors to explore and heighten the contradictions in a character's behavior. He would invite actors to stop at crucial points in the performance and have them explain to the audience the implications of a character's choice. By doing so, he wanted the public to become aware of the social implications of everyone's life choices. Like Brecht, we are interested in performances which produce awakening and reflection in the public rather than uncritical immersion. We therefore have organized our technology to augment the stage in a way similar to how "Mixed Reality" enhances or completes our view of the real world. This contrasts the work on Virtual Reality, Virtual Theater, or Virtual Actors which aims at replacing the stage and actors with virtual ones, and at involving the public in an immersive narration similar to an open-eyes dream.

English director Peter Brook, a remarkable contemporary, has accomplished a creative synthesis of the century's quest for a novel theory and practice of acting. Brook started his career directing "traditional" Shakespearean plays and later moved his stage and theatrical experimentation to hospital, churches, and African tribes. He has explored audience involvement and influence on the play, preparation vs. spontaneity of acting, the relationship between physical and emotional energy, and the usage of space as a tool for communication. His work, centered on sound, voice, gestures, and movement, has been a constant source of inspiration to many contemporaries, together with his thought-provoking theories on theatrical research and discovery. We admire Brook's research for meaning and its representation in theater. In particular, we would like to follow his path in bringing theater out of the traditional stage and perform closer to people, in a variety of public and cultural settings. Our virtual theater enables social networking by supporting simultaneous participants in human-to-human social manner.

Flavia Sparacino at the MIT Media Lab created the Improvisational Theater Space [23, 25], which embodied human actors and Media Actors to generate an emergent story through interaction among themselves and the public. An emergent story is one which is not strictly tied to a script. It is the analog of a "jam session" in music. Like musicians who play together, each with their unique musical personality, competency, and experience, to create a musical experience for which there is no score, a group of Media Actors and human actors perform a dynamically evolving story. Media Actors are autonomous agent-based text, images, movie clips, and audio. These are used to augment the play by expressing the actor's inner thoughts, memory, or personal imagery, or by playing other segments of the script. Human actors use full body gestures, tone of voice, and simple phrases to interact with media actors. An experimental performance was presented in 1997 on the occasion of the Sixth Biennial Symposium on Arts and Technology [24].

3.3 New Media Art and Interactive Theater

The first theater experiences at the ancient Greek culture (the fifth century BC) were developed based on the Dionysius experience, where the difference between public and scene did not exist; where there was no difference from public and actor because everybody participated with the same hierarchy in the event. During the twentieth century, theater experienced many changes and contemporary representations have been conceived without scenario, even without chairs, and with public and actors freely moving around the space and interacting between them.

Now, at the twenty first century, the new media technologies are bringing new exciting possibilities to the interactive theater field. Locative media, wearable computers and augmented reality are drastically changing the space of representation. New media art, psychogeography, networking, etc. are merging with contemporary theater to form a hybrid between creation, representation, and unique user experience. In new media interactive art installations, the user's experience is always different as it is generated for the user himself. Every user has a different experience as the piece is created differently every time. Theater has many relations with this because traditional theater experiences are also different depending on the context, the audience, and on the cultural reference of the people who see the representation. Some examples will now be described:

1. Interaction of actor–spectator through a technological device, for example, Epizoo Marceli Antunez Roca. Performance in which the audience can directly manipulate his body via a computer mouse. In his "Epizoo" performance, actuators attached on performer's body are controlled by audience using a mouse, which moves a variety of corresponding body parts, including the buttocks, nose, pectoral muscles, mouth, and ears to generate different graphics. The audience and the performer become linked in a circular interaction with technology, providing a real time experience in the limits and excesses of interpersonal control.
2. Locative Media. Spatial Narrations. Development in locative technology. This location-based system takes place in the space of a city, and the spectator must walk to different areas to experience different scenes, becoming an active actor in the theater experience. Examples: Teri Rueb choreographies. The AR Facada [8] from Georgia Institute of Technology is a mixed physical/virtual AI-based drama using these new media technologies. The audience as a friend is invited over for a drink at a make-or-break moment in the collapsing marriage of the virtual friends – Trip and Grace. He/She can move through a physical apartment and interact with the life-size virtual characters via gesture, speech and physical movement. The audience can assume different roles such as councilor and devil's advocate, and every audience will have different experiences.

3.4 Background

The goal of interactive theater is to provide actors (real and virtual) with different possible actions and to include audiences in the performance. The new media technologies are combined with ambient intelligent to achieve this aim.

3.4.1 Embodied Mixed Reality Space

In order to maintain an electronic theater entertainment in a physical space, the actors and props will be represented by digital objects, which must seamlessly appear in the physical world. This can be achieved using the full mixed reality spectrum of physical reality, augmented reality and virtual reality.

Furthermore, to implement human-to-human social interaction and physical interaction as essential features of the interactive theater, the theory of embodied computing is applied in the system, as described in Chap. 1.

Interactive theater in embodied mixed reality space is an exploration of embodied interaction within a mixed reality collaborative setting. The result of the project is a unique electronic theater which combines the interactions of natural human-to-human, human-to-physical world and human-to-virtual world, and provides a novel theater experience ranging from physical reality, augmented reality, to virtual reality.

3.4.2 Live 3D Actors

As mentioned above, this research aims to maintain human-to-human interaction such as gestures, body language, and movement between users. Thus, we have developed a live 3D interaction system for viewers to view live human actors in a mixed reality environment. At the same time, live human actors respond to viewers interactions to decide the new actions and bring different experience to different viewers. In fact, science fiction has presaged such interaction in computing and communication. In 2001: A Space Odyssey, Dr. Floyd calls home using a videophone – an early on-screen appearance of 2D video-conferencing. This technology is now commonplace. More recently, the Star Wars films depicted 3D holographic communication. Using a similar model, in this chapter we apply computer graphics to create real-time 3D human actors for mixed reality environments.

One goal of this work is to enhance the interactive theater by developing a 3D human actor capture mixed reality system. The enabling technology is an algorithm for generating arbitrary novel views of a collaborator at video frame rate speeds (30 frames per second). This technology has been presented in [17]. We also apply these methods to communication in virtual spaces. We render the image of the collaborator from the viewpoint of the user, permitting very natural interaction such as gesture and physical.

3.4.2.1 Hardware Setup

Figure 3.1 represents the overall structure of the 3D capture system. Eight Dragonfly FireWire cameras, operating at 30 fps, 640 × 480 resolution, are equally spaced around the subject, and one camera views him/her from above. Three Sync Units from Point Grey Research are used to synchronize image acquisition of these cameras across multiple FireWire buses [16]. Three Capture Server machines receive the three 640 × 480 video-streams in Bayer format at 30 Hz from three cameras each, and pre-process the video streams.

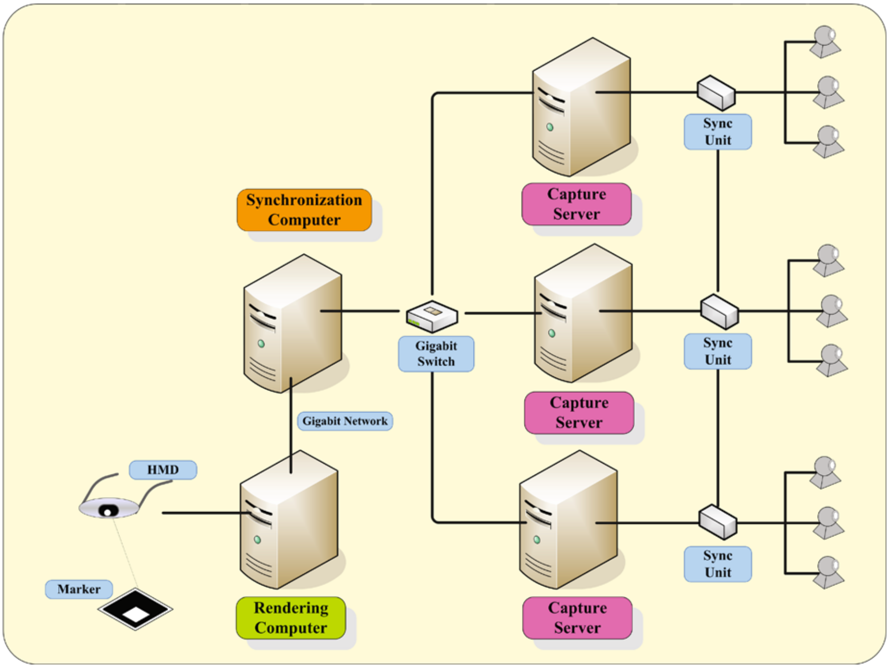

Fig. 3.1 Hardware architecture

The Synchronization machine is connected to the three Capture Sever machines through a Gigabit network. This machine receives nine processed image streams from three Capture Server machines, synchronizes them, and sends them also via gigabit Ethernet links to the Rendering machine.

At the Rendering machine, the position of the virtual viewpoint is estimated. A novel view of the captured subject from this viewpoint is then generated and superimposed onto the mixed reality scene.

3.4.2.2 Software Components

All of the basic modules and the processing stages of the system are represented in Fig. 3.2. The Capturing and Image Processing modules are placed at each Capture Server machine.

Image Processing module extracts parts of the foreground objects from the background scene to obtain the silhouettes after the Capturing module obtains raw images from the wlinecameras, compensates for the radial distortion component of the camera mode, and applies a simple compression technique.

Background subtraction as pre-processing step is one of the most crucial steps to determine the quality of the final 3D model. Not only having to produce the correct foreground object, the chosen background subtraction algorithm must be very fast

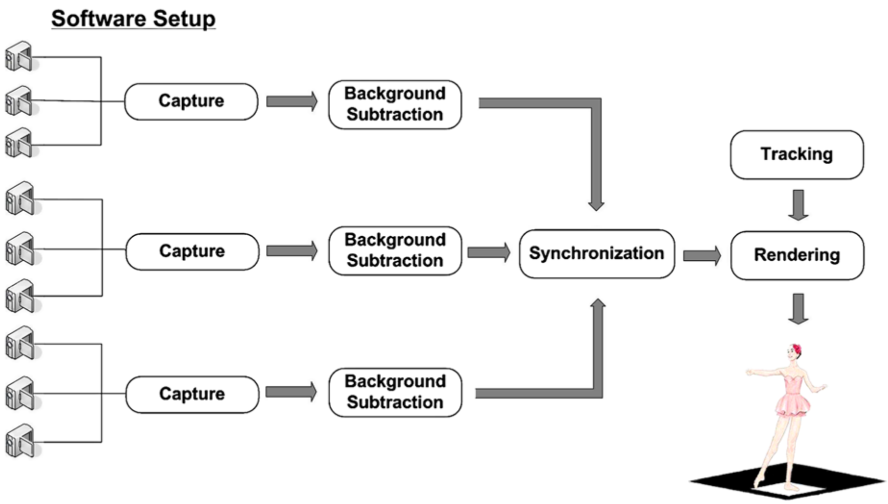

Fig. 3.2 Software architecture

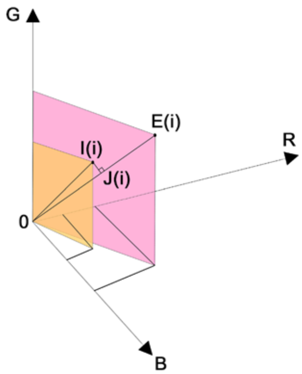

Fig. 3.3 Color model

to fulfill the real time requirement of this system. Another important requirement to guarantee the quality of the final 3D model is that the background subtraction algorithm must be able to eliminate the shadow caused by the objects. A modified method based on the scheme of Horpraset [13] is used to meet the requirement. This scheme has the good capabilities of distinguishing the highlighted and shadow. For our application, we only need to distinguish the "foreground" type from the rest, a new color model with separates the brightness from the chromaticity component is used as shown in Fig. 3.3.

Referring to Fig. 3.3, in the RGB color space, the point $I(i)$ represents the color value of pixel $i_t h$, and $E(i)$ represents the expected color value of this pixel, which coordinates $(\mu_R(i), \mu_G(i), \mu_B(i))$ are the mean values of the R, G, B components of this pixel obtained from the learning stage. $J(i)$ is the projection of $I(i)$ on the line $OE(i)$.

The color distortions (CD_i) of this pixel are defined and calculated as:

$$CD_i = \mathrm{sqrt}\left(\frac{I_R(i) - \alpha_i \mu_R(i)}{\sigma_R(i)}\right)^2 \left(\frac{I_G(i) - \alpha_i \mu_G(i)}{\sigma_G(i)}\right)^2 \left(\frac{I_B(i) - \alpha_i \mu_B(i)}{\sigma_B(i)}\right)^2. \tag{3.1}$$

In the above formula, $\sigma_R(i)$, $\sigma_G(i)$, $\sigma_B(i)$ are the standard deviations of the i_th pixel's red, green, blue values computed in the learning stage. In our version, we assume that the standard deviations are the same for all pixels, to make CD_i formula simpler:

$$CD_i = \big(I_R(i) - \alpha_i \mu_R(i)\big)\big(I_G(i) - \alpha_i \mu_G(i)\big)\big(I_B(i) - \alpha_i \mu_B(i)\big). \tag{3.2}$$

Another assumption is that the distributions of α_i and CD_i are the same for every pixel i. With this assumption, we do not need to normalize α_i and CD_i as was done in [13].

These modifications reduce the complexity of the formula and quite drastically increase the calculation speed from 33 ms/frame to 13 ms/frame, but produce more small misclassified pixels than the original algorithm. However, these small errors can be easily filtered.

Another important part that needs to be handled is the data size for real-time network transfer which can also be handled in the Image Processing module. We use two methods to optimize the data size: only storing the smallest rectangular region containing the foreground objects and using Bayer format [19] with background information encoded to store the images, which costs only 1 byte for each pixel.

The Synchronization module, on the Synchronization machine, is responsible for getting the processed images from all the cameras and checking their timestamps to synchronize them. The data received from the Image Processing module include three parts: the smallest rectangle area that contains the silhouette of the image which is processed by the Image Processing module; the pixel-weights for this image and the Time Stamp. Once one set of an image is received, the time stamp of each image will be compared to check the synchronization. If those images are not synchronized, the Synchronization module will request the slowest camera to continuously capture and send back images until all these images from all nine cameras appear to be captured at nearly the same time.

The Tracking module calculates the Euclidean transformation matrix between a live 3D actor and the user's viewpoint. This can be done either by marker-based tracking techniques [2] or other tracking methods, such as sensor tracking.

The Rendering module will generate a novel view of the subject based on those images received from the Synchronization module and the transformation matrix received from the Tracking module. The novel image is generated such that the virtual camera views the subject from exactly the same angle and position as the head-mounted camera views the marker. This simulated view of the remote collaborator is then superimposed on the original image and displayed to the user. The algorithm proceeding entirely on a pre-pixel basis is used for rendering, and three operations are needed to be performed for each virtual pixel: determining the depth

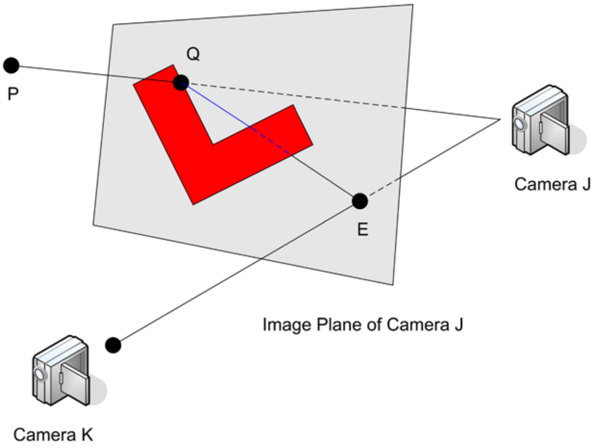

Fig. 3.4 Visibility computation: since the projection Q is occluded from the epipole E, 3D point P is considered to be invisible from camera K

of the virtual pixel as seen by the virtual camera, finding corresponding pixels in nearby real images, and determining pixel color based on all these measurements.

To increase the speed and get better quality, new occlusion detection algorithm and color blending method are chosen. To compute visibility, Matusik introduced a novel algorithm which can effectively reduce 3D visibility computation to the 2D visibility computation [15] and use it to determine visibility of each face of the visual hull. In our system, we use this algorithm to compute visibility of each point of the image-based visual hull. Our algorithm can be explained using Fig. 3.4. To determine if a point P is visible from a camera K, the three following steps will be processed:

1. Find one camera J where the projection Q of P lies on the edge of the silhouette.
2. Find the epipole E of camera K on the image plane of camera J.
3. If there is any foreground pixel lying on the line connecting point Q and point E, i.e., Q is occluded from point E, then P will be considered to be occluded from camera K. Otherwise, P will be considered to be visible from camera K.

To reduce the error on the edge caused by the background subtraction, we take a weighted average with pixels near the center of each silhouette having higher weights. This makes the visual hull smoother along the edges of silhouettes. The problem with this blending method is that it requires more memory and time to store and calculate the weights for each pixel of each reference where images got different weights. To increase the speed, we calculate them during the image processing process then pass the result to the rendering module as mentioned above, thus we can run this calculation on three different computers and triple the speed.

In the interactive theater, using this system, we capture live human models and present them via the augmented reality interface at a remote location. The result gives the strong impression that the model is a real three-dimensional part of the scene.

3.4.3 Ambient Intelligence

Ambient Intelligence (AmI) integrates concepts ranging from ubiquitous computing to autonomous and intelligent systems. AmI is the vision that technology will become invisible, embedded in our natural surroundings, present whenever we need it, attuned to all our senses, adaptive to users and context and autonomously acting. High quality information and content must be available to any user, anywhere, at any time, and on any device.

In an Ambient Intelligent environment [27], people are surrounded with networks of embedded intelligent devices that provide ubiquitous information, communication, services, and entertainment. Furthermore, the device adapt themselves to users, and even anticipate their needs. Ambient intelligent environments present themselves quite differently compared to contemporary handheld or stationary electronic boxes and devices. Electronics will be integrated into clothing, furniture, cars, houses, offices, and public places, introducing the problem of developing new user interface concepts that allow natural interaction with these environments. AmI environments are designed for people, not generic users. This means that the system should be flexible and intelligent to tailor its communication facilities to increase the usability of the system by enhancing our senses. A promising approach is the one in which users interact with their digital environments in the same way as they interact with each other. Reeves and Nass were the first to formulate this novel interaction equivalence, and they called it the Media Equation [18]. *The information environments are the major drivers of culture*.

MIT's Oxygen project [7] and IBM's effort on pervasive computing [22] are similar approaches addressing the issue of integration of networked devices into peoples' backgrounds. Ambient Intelligence (AmI) aims at taking the integration even one step further by realizing environments that are sensitive and responsive to the presence of people. The focus is on the users and their experience from a consumer electronics perspective, which introduces several new basic problems related to natural user interaction and context-aware architectures [1] supporting human-centered information, communication, service, and entertainment [14].

AmI covers a whole world of underlying technologies used to process information: software, storage, displays, sensors, communication, and computing. To identify such vastly different devices that are needed to realize ambient intelligent environments, we first introduce a scenario that facilitates the elicitation of a number of essential ambient intelligent functions from which device requirements can be determined.

AmI vision requires an intensive and carefully planned integration of many different and highly advanced technologies. These technologies may range from energy-efficient, high performance computing platforms, powerful media processing hardware and software to intelligent sensors and actuators, and advanced user-interface designs (vision, speech).

The highly dynamic AmI environments, along with tightening cost and time-to-market constraints for various AmI products, require that the enabling technologies for products be highly scalable in almost every aspect. For instance, an interactive,

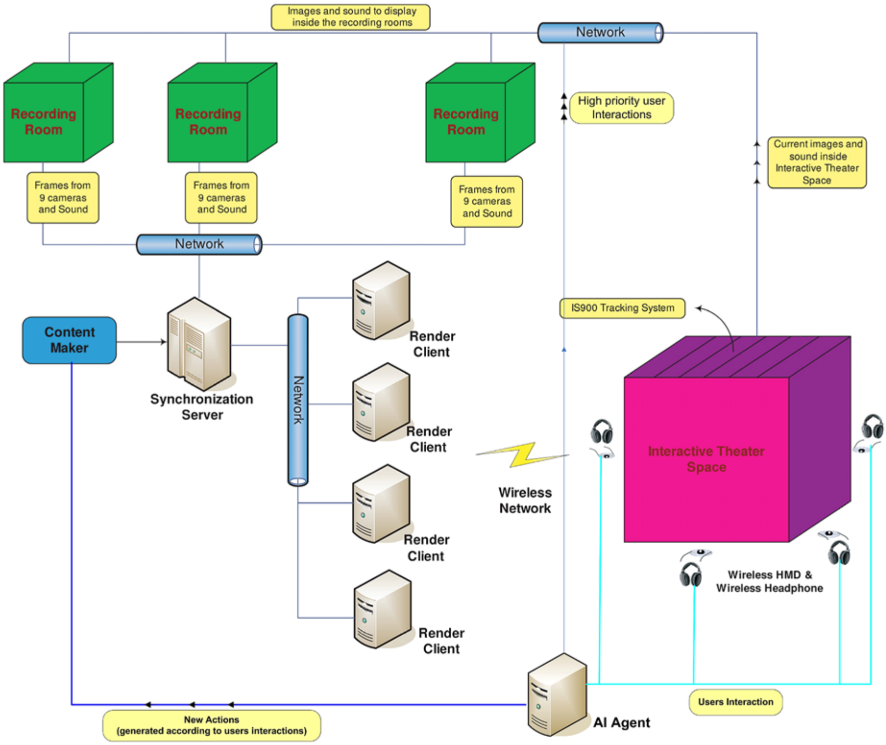

Fig. 3.5 Interactive Theater System

multi-player gaming device must be able to seamlessly adapt to constantly changing networking conditions; a new generation of a high-end residential gateway must be introduced in the market without the necessity to redesign the processing infrastructure from scratch. In our system, video based tracking is used to track the audience to start/activate a drama and respond to the gestures to generate a different story line.

3.5 Interactive Theater System

In this section, we will introduce the design of our Interactive Theater System. The diagram in Fig. 3.5 shows the whole system architecture.

3.5.1 3D Live Capture Room

3D Live capture rooms are used to capture actors in real time. Basically, these are the capturing part of 3D Live capture system, which has been described in Sect. 10.4.

Fig. 3.6 Actor playing Hamlet is captured inside the 3D Live recording room

The actors play inside the 3D Live recording room, and their images are captured by 9 surrounding cameras. After subtracting the background, those images are streamed to the synchronization server using RTP/IP multicast, well-known protocols to transfer multimedia data streams over the network in real time.

Together with the images, the sound is also recorded and transferred to the synchronization server using RTP in real time. This server will synchronize those sound packets and images, and stream the synchronized data to the render clients, also using RTP protocol to guarantee the real time constraint. While receiving the synchronized streams of images and sounds transferred from the synchronization server, each render client buffers the data and uses it to generate the 3D images and playback the 3D sound for each user.

One important requirement of this system is that the actors at each recording room need to see the story context. They may need to follow and communicate with actors from other recording rooms, with the virtual characters generated by computers, or even with audiences inside the theater to interact with them. In order to achieve this, several monitors are put at specific positions inside the recording room to reflect the corresponding views of other recording rooms, the virtual computer generated world, and the current images of the audiences inside the theater. The actors and dancers only need to respond to remote actors, dancers and audiences by gesture, speech, etc.; they do not need to consider the position, which will be handled by the integration part. The system will consider the previous positions of all actors/dancers and the story development to set new positions for all virtual remote characters. Those monitors are put at fixed positions so that the background subtraction algorithm can easily identify their area in captured images and eliminate them as they are parts of the background scene.

Figure 3.6 shows an example of the recording room, where an actor is playing Hamlet.

Fig. 3.7 Interactive Theater Space in VR mode: 3D Live actor as Hamlet in virtual environment

3.5.2 Interactive Theater Space

The Interactive Theater Space allows the audiences to view the story in high resolution 3D MR and VR environments. Inside this space, we tightly couple the virtual world with the physical world.

The system uses IS900 (InterSense) inertial-acoustic hybrid tracking devices mounted on the ceiling. While visitors walk around in the room-size space, their head positions are tracked by the tracking devices. We use the users' location information to interact with the system, so that the visitors can actually interact with the theater context using their bodily movement in a room-size area which incorporates the social context into the theater experience.

The Interactive Theater Space supports two experience modes: VR and MR modes. Each user wears a wireless HMD and a wireless headphone connected to a render client. Based on the user's head position in 3D, which is tracked by the IS900 system, the render client will render the image and sound of the corresponding view of the audience so that the audience can view the MR/VR environment and hear 3D sound seamlessly embedded surrounding her.

In the VR experience mode, featured with fully immersive VR navigation, the visitors will see that they are in a virtual castle and they need to navigate inside it to find the story performed by the 3D live actors. For example, in Fig. 3.7, we can see the live 3D images of the actor playing Hamlet in the Interactive Theater Space in VR mode with the virtual grass, boat, trees, and castle. The real actors can also play with imaginative virtual characters generated by computers, as shown in Fig. 3.8.

As a result, in VR mode, the audiences are surrounded by characters and story scenes. They are totally submerged into an imaginative virtual world of the play in 3D form. They can walk or turn around to view the virtual world at any view point, to see different parts and locations of the story scene, and to follow the story according to their own interests.

Besides VR mode, users can also view the story in MR mode, where the virtual and real worlds mix together. For example, the real scene could be built inside the room or outdoors, with real chairs, tables, etc., but the actors are 3D virtual live characters captured inside the 3D Live recording rooms at different places. Figure 3.9 shows a view of an audience in MR mode, where she can see the captured 3D live actors in the real physical environment. In this case, the positions of the 3D virtual

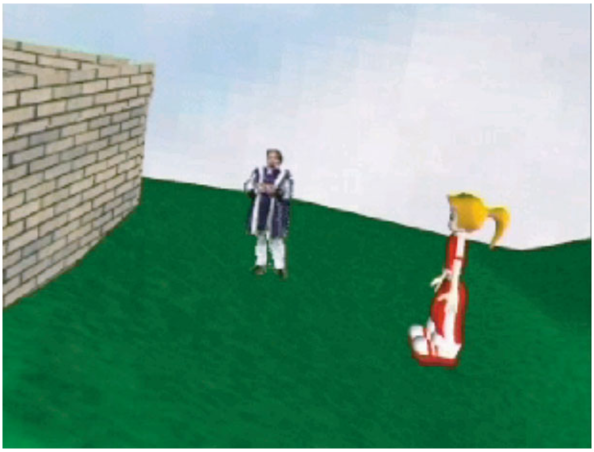

Fig. 3.8 Interactive Theater Space in VR mode: 3D Live actor as Hamlet playing with virtual character

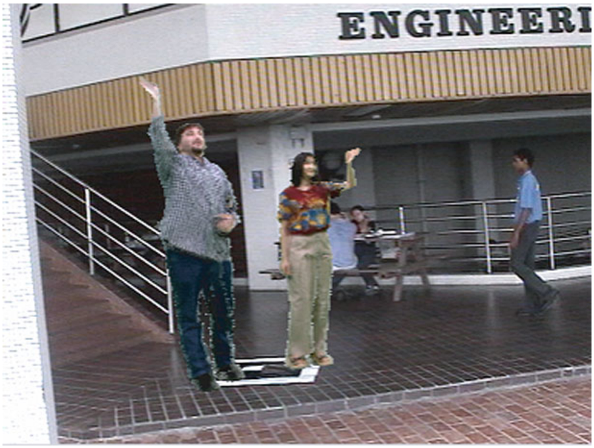

Fig. 3.9 Interactive Theater Space in MR mode

live actors are decided by the marker tracked by camera attached on audience's head mounted display.

Moreover, our Interactive Theater system enables actors from different places to play together at the same place in real time. With the real time capturing and rendering feature of 3D Live technology, using RTP/IP multicast to stream 3D Live data in real time, people at different places can see each other as if they were at the same location. With this feature, dancers from many places all over the world can dance together via Internet, and their 3D images are displayed at the Interactive Theater Space corresponding to the users' viewpoints, tracked by marker. As shown in Fig. 3.10, two dancers from different locations are captured and displayed in the

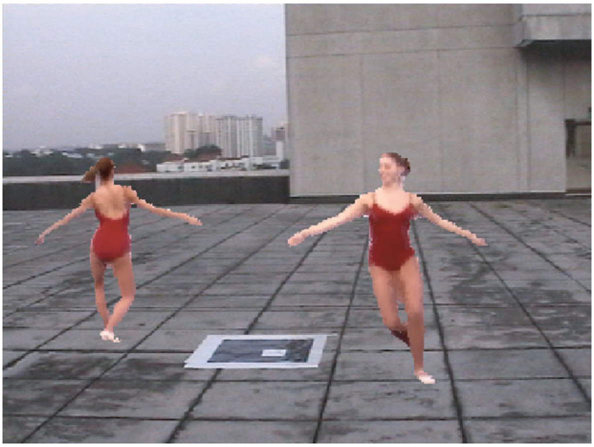

Fig. 3.10 Interactive Theater Space in MR mode

outdoor MR dance area. The AI Agent module in Fig. 3.5 handles all the user interactions to generate the optimal actions for virtual character and chooses the top priority interactions for physical actors to respond (we will give a detailed introduction of user interaction in next section), then the new actions are send to Content Maker module and the selected interactions are send to corresponding physical actors. The Content Maker module in Fig. 3.5 defines the story outline, scene by specifying the locations, actions generated by AI agent of virtual characters, and interactions of 3D Live actors.

3.5.3 System Interaction Design

Three types of interactions are supported by our interactive theater system as shown in Fig. 3.11:

- Interaction between audiences and physical 3D live actors by speech, gesture, and physical movement.
- Interaction between audiences and virtual characters by speech, gesture, and physical movement.
- Interaction between physical 3D live actors and virtual characters by speech and gesture.

In order to enable the interaction of the audiences and the actors at different places, several cameras and microphones are put inside the Interactive Theater Space to capture the images and voices of the audience. Those images and voices captured by the cameras and microphones will be sent to the AI agent to process. The AI agent needs to process user interactions for both virtual characters and 3D Live actors. For virtual characters, both the user interactions and 3D Live actors' actions are calculated by AI agents to generate optimal actions and send to the content

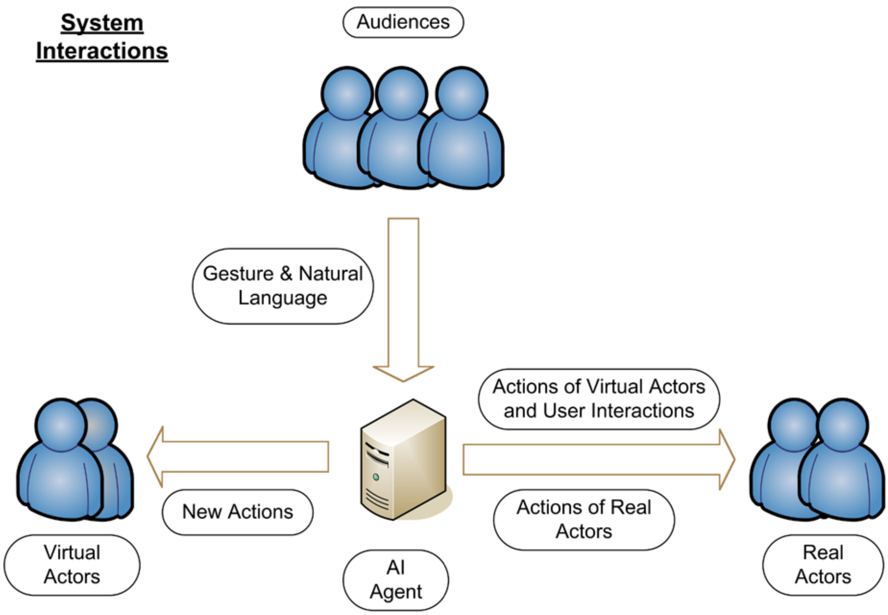

Fig. 3.11 System Interaction Design

maker to generate new scenarios. For 3D Live actors, gesture recognition and priority sorting algorithm are used to determine meaningful high priority interactions after which the results will be transferred to the displays of the corresponding actors' recording rooms. Consequently, the actors can see the audiences' interactions and give the responses to them following pre-defined story situations. As a result, the users can walk around inside the Interactive Theater Space to follow the story, interact with both real and virtual characters, and use their own interactions to change the story within the scope of the story outline. Figure 3.12 shows the framework of how user interactions are handled.

3.5.4 3D Sound in Interactive Theater Space

Spatial sound [20, 21, 28], sometimes termed "3D sound," is sound as we hear it in our daily life. Spatial sound has been arranged or processed to give a listener the sense of the location of real or virtual sound sources and the characteristics of a virtual listening space. Spatial audio technology enables people to perceive a sound as being emitted from a certain direction in space by applying filters to the sound signal. Spatial audio in the interactive theater space can greatly enhance the user experience due to the fact that it enables directional hearing, thus allowing users to perceive the direction of sounds in the virtual theater stage. Such an effect is

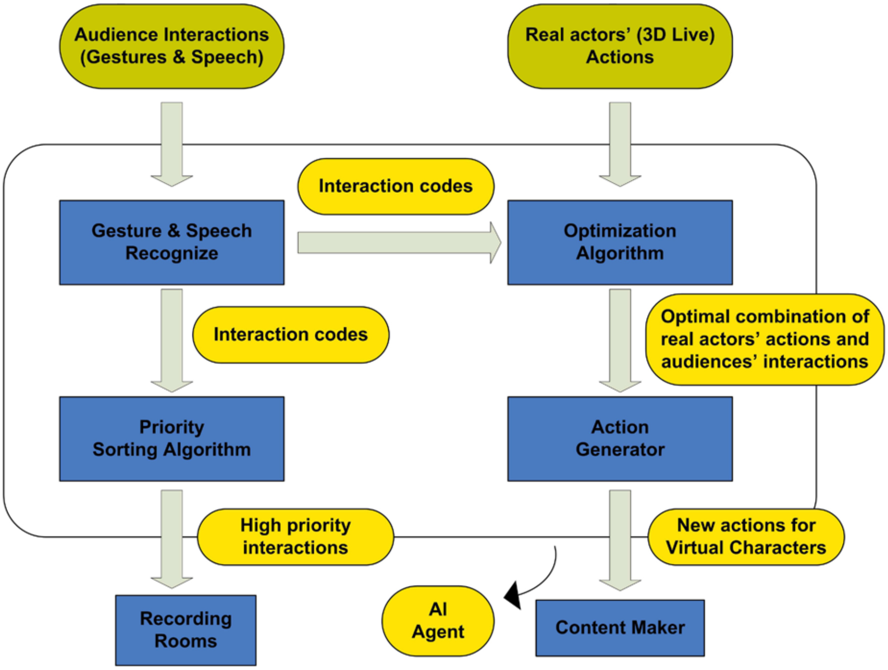

Fig. 3.12 The framework of users' interaction

beneficial both from perceptual as well as from a usability and user experience and satisfaction points of view.

The 3D sound APIs [26] enable the development of more realism in virtual environments, especially in computer games, by adding positional and dynamic sound sources. Besides geometry-based graphics, Java 3D[1] also includes 3D spatial sound, which is not commonly considered a part of a graphics environment. In a similar way as a VRML scene [4], a Java 3D application is programmed in a form of a scene graph. However, its spatial sound properties are more advanced enabling reverberation, air absorption, and frequency dependent directivity definitions. This functionality helps us develop more immersive experience in virtual space.

We used Java 3D spatial sound capabilities to develop such sound spatialization in our virtual environments. The Java 3D class Sound is abstract and has subclasses BackgroundSound, PointSound, and ConeSound. The PointSound node, which is used in our system, defines a spatially-located sound whose waves radiate uniformly in all directions from some point in virtual space. It has the same attributes as a sound object with the extension of a location and the specification of distance-based attenuation for listener positions using an array of distances and gains. The sound's

[1] java.sun.com/products/java-media/3D/.

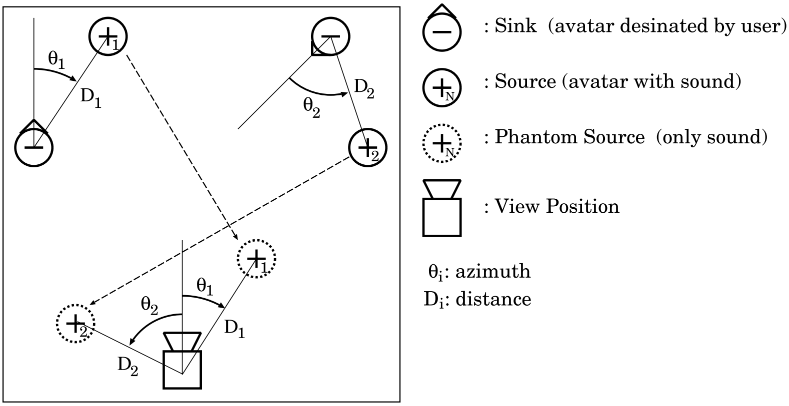

Fig. 3.13 Phantom source

amplitude is attenuated based on the distance between the listener and the sound source position. A distance-dependent attenuation region is defined by ellipsoids. Sounds added to a virtual environment have no distance attenuation associated with them by default. However, developers can define a distance attenuation curve, the relationship between sound's acoustic gain and its distance from the listening position. Linear interpolation is used to determine points between the programmer-specified points. Therefore, more points lead to greater resolution in the attenuation curve. However, Java 3D listening point is implicitly associated with the virtual camera position (viewpoint). Our technique is to relocate sources to compensate for the selected viewpoint.

Phantom sources [9] are used to control superposition of soundscapes relative to a selected viewpoint. Relative displacement from sources to sinks can be used to display phantom sources from alternate locations, exocentrically visibly and endocentrically auditorilly. Logical separation of the view point and listening point is used to overcome Java 3D assumptions and make the interface more fluid. Phantom sources manifest visually, displayed relative to a virtual avatar, and sonically, spatial sound invisibly offset relative to the current view point (virtual camera). Further, adjusting the displacement of the phantom source, a rotated speaker axis can be accommodated. For instance, if stereo speakers are normally arranged on the frontal plane, rotating the offset of the phantom source can preadjust the Java 3D spatialization for speakers arranged "frontally," i.e., on the median plane.

The phantom source function calculates the azimuth (3.3) and distance (3.5) between the sound source and sink, and then reconstructs soundscapes around the view position (Fig. 3.13). θ is the azimuth of the best sink for the sound source. φ is a selectable angle of 0° or 90° to implement the rotatable speaker axis arrangement.

$$azimuth = \arg\left(\overrightarrow{source}_x - \overrightarrow{sink}_x,\ \overrightarrow{source}_y - \overrightarrow{sink}_y\right) - \theta_{sink} + \varphi, \tag{3.3}$$

$$\arg(x, y) = \begin{cases} \tan^{-1}\left(\frac{y}{x}\right) & (x > 0) \\ \tan^{-1}\left(\frac{y}{x}\right) + \pi & (x < 0,\ y > 0) \\ \pi & (x < 0,\ y = 0) \\ \tan^{-1}\left(\frac{y}{x}\right) - \pi & (x < 0,\ y < 0) \\ \frac{\pi}{2} & (x = 0,\ y > 0) \\ \text{undefined} & (x = 0,\ y = 0) \\ -\frac{\pi}{2} & (x = 0,\ y < 0), \end{cases} \tag{3.4}$$

$$distance = \sqrt{\left(\overrightarrow{source} - \overrightarrow{sink}\right)^2}. \tag{3.5}$$

From a perceptual point of view, a big contribution is that spatial sound enables alleviating the problem of masking. More specifically, it is useful to mention that when watching virtual theater, the users are faced with selective and divided attention hearing tasks. Divided attention tasks are those in which spectators must follow more than one audio information stream at a time. Selective attention tasks are where attention is focused on only one of multiple information streams. For example, listening simultaneously to two speakers in a teleconference scenario is a divided selection task since the user is required to understand the 'meaning' conveyed by both speakers. On the other hand, focusing on the content of one speaker in the presence of others is a selective attention task since the spectator has to focus on the selected speaker with the rest of the speakers acting as distracters. The narrowcasting operations [6] described in next paragraph suggest an elegant solution for such selective and divided attention environments.

Non-immersive perspectives in virtual environments enable flexible paradigms of perception, especially in the context of frames-of-reference for conferencing and musical audition. Traditional mixing idioms for enabling and disabling various audio sources employ `mute` and `solo` functions which selectively disable or focus on respective channels. Previous research [6] defined sinks as duals of sources in virtual spaces, logical media stream receivers, along with symmetric analogs of source `select` and `mute` attributes. Interfaces which explicitly model not only sources, but also sinks, motivate the generalization of `mute` & `select` (or `cue` or `solo`) to `exclude` and `include`, manifested for sinks as `deafen` & `attend` (`confide` and `harken`), as elaborated by Fig. 3.14.

Narrowcasting functions which filter stimuli by explicitly blocking out and/or concentrating on selected entities [10] can be applied not only to other users' sinks for privacy, but also to one's own sinks for selective attendance or presence. Narrowcasting attributes are not mutually exclusive, and the dimensions are orthogonal. Because a source or a sink is active by default, invoking `exclude` and `include` operations simultaneously on an object results in its being disabled. For instance, a sink might be first `attended`, perhaps as a member of some non-singleton subset of a space's sinks, then later `deafened`, so that both attributes are simultaneously applied. (As audibility is assumed to be a revocable privilege, such a seemingly conflicted attribute state disables the respective sink whose attention would be restored

The general expression of inclusive selection is

$$\texttt{active}(x) = \neg\texttt{exclude}(x) \ \wedge \ \left(\exists\, y \,(\texttt{include}(y) \wedge \left(\texttt{self}(y) == \texttt{self}(x)\right)\right) \ \Rightarrow \ \texttt{include}(x)\right). \qquad (3.6)$$

So, for `mute` and `select` (`solo`), the relation is

$$\texttt{active}(\text{source } x) = \neg\texttt{mute}(x) \ \wedge \ \left(\exists\, y \left(\texttt{select}(y) \wedge \left(\texttt{self}(y) == \texttt{self}(x)\right)\right) \ \Rightarrow \ \texttt{select}(x)\right), \qquad (3.7a)$$

`mute` explicitly turning off a source, and `select` disabling the collocated (same window/room/space) complement of the selection (in the spirit of "anything not mandatory is forbidden"). For `deafen` and `attend`, the relation is

$$\texttt{active}(\text{sink } x) = \neg\texttt{deafen}(x) \ \wedge \ \left(\exists\, y \left(\texttt{attend}(y) \wedge \left(\texttt{self}(y) == \texttt{self}(x)\right)\right) \ \Rightarrow \ \texttt{attend}(x)\right). \qquad (3.7b)$$

Fig. 3.14 Formalization of narrowcasting and selection functions in predicate calculus notation, where '¬' means "not," '∧' means conjunction (logical "and"), '∃' means "there exists," and '⇒' means "implies"

upon resetting its `deafen` flag.) Symmetrically, a source might be `selected` and then `muted`, akin to making a "short list" but relegated to backup.

Narrowcasting attributes can be applied interactive theater more meaningful way. People can actively be involved in a more than one scene in the drama either as actors/actresses or as spectators. For instance, an actor/actress can play one role in a scene and provide his/her voice to another scene while listening to instructions for the next role. Spectators can see a scene of the drama while listening to another scene which is out of their visuals. More specifically, they can attend different actors/actress in different scenes according to their preferences using narrowcasting attributes.

Cinematically, diegetic sound is the sound whose source is visible on the screen or whose source is implied to be present – including voices of characters (dialog), sounds made by objects in the story space (like Foley effects), and music represented as coming from instruments or singers in the story space (a.k.a. "source music") – whereas nondiegetic sound has a notional source understood to be somehow outside the visually depicted space, including "meta-sound" like narrator's commentary or voice-over and interior monologues, sound effects added for dramatic effect, and mood or theme music,[2] including bridge music spanning scene transitions.

This distinction might not always be clear, especially since diegetic sound may be on- or off-screen (depending on whether its source is within or beyond the viewing frame). For example, exaggerated effects might push beyond literal "earcon"s [11] to approach abstract, emotional, or symbolic interpretations. One of the conceits of media soundtracks is that plausibility is not undermined nor belief unsuspended when on-screen action is accompanied by music (or laugh-tracks, or applause, etc.), obviously separate from the story space, a metaphysical juxtaposition that would be jarring if we were not so accustomed to it. In Mel Brooks' movie "Blazing Saddles," ensemble music for a scene at a cowboy camp is reasonably assumed to be nondiegetic, mood music for the audience, presumed to be inaudible

[2] www.filmsound.org/terminology/diegetic.htm.

to the characters, only to be revealed by a panning frame as being played by musicians absurdly installed into the campsite, and therefore amusingly surprisingly diegetic. Like Woody Allan or the creative team of Zucker/Abrams/Zucker – who made the "Airplane," "Naked Gun," and "Top Secret" movie series – Brooks enjoys literally deconstructionist jokes, which wittily illuminate the fragility of cinematic convention stretched across self-referential loops.

As another example of a difficult-to-classify source, the voice of an on-screen character might be recognized as a reminiscence, perhaps a framing for a flash-back narrated by an older self, speaking, as it were, from a different space, and unheard by other on-screen characters. (In the movie "Reversal of Fortune," the narrator addresses the audience from a deep coma!)

Narrative arts – plays, movies, story telling, etc. – have always experimented to varying degrees with breaking down the "4th wall," the understood distinction between the respective domains of the performers and the audience. A character might address the audience directly, or a play-within-a-play, as in Hamlet, suggests regresses of acting, simultaneously acknowledging the artifice of the performers, while also hinting at the acting roles assumed by the audience. "All the world's a stage," but also the theatrical stage projects out into "the real world." Like a Greek chorus commenting on the drama, the "Stage Manager" in Thorton Wilder's "Our Town" straddles the divide between the audience and the performer.

Contemporary "post-modern" approaches have made such issues explicit. One important quality that distinguishes post-modern media is its explicit use of quotes, references to other works that inform and contextualize the ironic story. In such a context, "irony" goes beyond its simpler denotations of perverse coincidence or sarcasm to be understood as self-consciousness, as when a character lets the audience know that he knows he is in a play. For example, satirical stories assume that the audience is familiar with other instances of whatever genre, and has internalized that genre's cliches, so that the plot can play off such expectations.

A good story resolves the tension between the impulse to make it complicated and the impulse to make it tidy. Sensations of both surprise and inevitability are necessary. In order to seem satisfying, a story should conclude in some way that befits its exposition. "Machina ex deus," machines from God sent to force a solution to some conflict in the absence of a natural resolution are not satisfying to sophisticated audiences (although children seem content with abrupt happy endings, unbuttressed though they may be by premonitions or suggestions of such a conclusion).

"If a gun appears in Act I, it will go off in Act III." Of course, any story teller wants to surprise the audience; otherwise the story would be boring.

Nowadays, synchronous directors' commentaries, interactive cinema (like "Clue"), audience-prompted improvisational theater blur the distinction between composition/direction/acting.

Such fuzziness notwithstanding, the taxonomy is practically useful since the desire for continuity and consistency encourages compatibility of whatever environmental media. Unless there is some other unusual consideration, it is most natural, for instance, to program similar room effects – qualitatively described by various attributes like ambiance, clarity, presence, reverberation, etc. – for collocated sources, and spatializing logically external sources as acoustically distinct from internal. (Auditory stream segregation infers sources based on gestalt properties of coherence and correlation between signals, synchronous timing, shared or related modulation, and "shared fate" [12].)

Such a notion is also usefully extended to audio for virtual environments, especially when such a groupware system is considered as a kind of interactive movie or distributed monitor. For simple if obvious example, the voices of avatars in a play's interior spaces, inside some model of a room, might have an echo, denied to those outside. An advanced theater system exploiting such idioms could, for extended example, apply different effects to voices belonging to speakers inside and outside an organization or group, conflating the ideas of interior/exterior and inside/outside, and treating a virtual architecture as analogous to logical organization by rendering metaphorical insiderness as literally inside a building. Of course, richer "piggy-back channel" arrangements are possible, but this simple example conveys the idea of logical space expressed as simulated virtual space.

For emotional or narrative, or artistic purposes, apparent consistency is more important than accurate or veridical auralization, and multimodal considerations are more important than purely acoustical. That is, what a user thinks and feels is more important than what that user sees or hears. The idiom and the vernacular "grammar of cinema" inform the interpretation of multimedia signs (camera shots and audio tracks being semiotic channels), and language is all about using previously understood associations, like the mapping between words and ideas, to construct new associations that reveal new ideas. Artists do not work in a vacuum; media artists, no less than verbal artists like writers, need to understand and assume the literacy of the audience, a pre-learned vocabulary in which target ideas can be expressed.

For instance, assuming the conventions of cinema sound (like audibility through understood invisible microphones placed before speakers' mouths), a mix might put a particular sound relative to a protagonist or in absolute space. A "talking head" close-up might center the single voice, but a two-person dialog might contrastingly pan the respective voices.

Even though various conventions for panning or spatializing sound for movies (like panning dialog into the center channel of a 5.1 system even if its source is offset from the center of the frame) confound a strictly literal sonic rendering of the space, the extra layer of indirection represented by the features described here suggest an even looser correspondence between the soundscape and what one might experience if, for example, binaural audio pairs captured by dummy-heads scattered through a real space combined (by simply adding in a stereo mixer, say). Because of this disconnect, we think of the sources so abstracted as pseudo-diegetic, having some (perhaps non-singular) origin in the portrayed space, but also mediated by abstract meta-considerations that motivate the qualifying prefix.

User satisfaction is greatly enhanced using spatial audio. This is due to the fact that the perceived theatrical event is more natural when sound is associated with space. If non-spatialized audio is used, the user will be confronted by contradicting evidence through his senses. Essentially, his vision will inform him about the presence of multiple display actors allocated at different positions across the stage;

however, his audition will suggest that all sound from the actors will come from the same display area. It is not hard to imagine what an unrealistic impression such a phenomenon will convey. It will be very hard for spectators to associate speech with actors, and they will have to use other visual mainly cues to infer which actor they must associate the sound they listened to. The phenomenon will be even more dramatic when non-speech sounds are considered. Footsteps, knocks, doors opening and closing cannot be perceived in a satisfactory way without being associated with a certain position in space.

3.6 Conclusion

In this chapter, we have explored future mixed reality, 3D Live, 3D sound and ambient intelligence technologies involving a new type of interactive theater where actors and dancers at different places can play and dance together at the same place in real time, and audiences can view and interact with them in 3D form. Our new Interactive Theater System is successful in bringing performance art to the people and offering the artists a creative tool to extend the grammar of the traditional theater. It also enables social networking and relations, by supporting simultaneous participants in human-to-human social manner. Except for the supporting technology, the related research about the history of virtual theater and interactive theater has been done as guidance of designing our interactive virtual theater system. Limited by the power of computer and the 3D data storage, transfer and rendering technologies, the current theater system cannot achieve high resolution 3D human size characters rendering. In the future, we will work on new 3D data storage, transfer and rendering algorithms to improve the resolution of human size 3D virtual character. To evaluate and improve the system further, user studies will be conducted focusing on usability of the system.

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Chapter 4
Metazoa Ludens: Mixed Reality Interaction and Play Between Humans and Animals

4.1 Introduction

Human–animal interaction offers many benefits for both the animals and humans [5, 41]. More often than not, the bonding shared between a human and his/her pet is such that the owner is as close to the pet as the owner is to his/her closest family member [2]. On the other hand, digital media interaction has been greatly enhanced by technological advancement. Nonetheless, such technologically enhanced interactions are generally restricted to human–human interaction and not extended to promote inter-species interaction.

Despite the lack of technological enhancement to human–animal interaction, the advancement of technology itself is changing the way people live, making life more efficient. Yet, on the other hand, longer working hours are expected in the professional world in order to match up with the higher level of efficiency (thus produced by technology) [21]. Due to this general change in the professional lifestyle [35], humans are out of the house for longer hours and often pets are generally neglected and taken for granted by the pets' owners. However, animals, like human beings, need love and care [30] as well as a good dose of exercise with a suitable diet to ensure healthy living [13]. With this negligence, pets will be deprived of the love and care they so required from their human families [30]. Thus there is a need to create an interface that is capable of allowing humans to shower their pets (especially smaller animals kept in cages) with attention locally or remotely; in addition the element of exercise may be incorporated into the system to add yet another beneficial feature for small pets.

This new interface could give a different form of and connectivity game play between human and small animals relative to existing ones. When the game play is in a form of mixed reality game, different forms of interaction may be introduced where the small animals are allowed to "chase after" the human owners instead in a digital world (this is impossible in the physical world). Such a game play may be even extended to remote interaction over the Internet. Metazoa Ludens is therefore devised. It hopes to allow interaction between human and small animals (like hamsters) through a digital interface in a mixed reality manner which is different from the conventional human–animal interaction.

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4.2 Objectives

Metazoa Ludens is a system that enables humans to play games with small animals in a mixed reality environment that provides all players (human and animal) with similar positions in the game. The desire to create this human–pet computer game system illustrates a way to reverse the trend of the growing lack of quality time between humans and pets. The aim is to create a media interface capable of remote human–animal interaction, taking into consideration the different physiological and psychological make-up between humans and their pets (especially smaller animals), and the way they may interact with the interface. It is also the aim of the project that the system will not only provide a way for humans to interact remotely with their smaller pets but also provide health benefits to the pets.

This research is aimed in general at mixed reality interactive play between humans and animals. In certain parts of the world, like Asia, where living spaces are smaller and larger animals like cats and dogs are not viable to be kept as pets, smaller animals like hamsters or fishes become the more popular choices. Small animals therefore become the target pets for our research system Metazoa Ludens. For the case of Metazoa Ludens, hamsters are specifically chosen because of the following advantages:

- In human houses, a hamster's running space is normally within its cage unlike dog's or cat's which normally can run and roam about the house and garden. Therefore, we want to encourage new media which will allow much more variety of in-house play for hamsters.
- Hamsters are a very popular pet choice and the most popular of the smaller rodents [33]. Therefore, we can create media which can be enjoyed by a wide range of society.
- Hamsters are economical and easy maintenance pets, and are kept by a wide range of society members including males and females, economically rich as well as poor [27].
- Hamsters have a natural instinct to be skillful intelligent runners, which is very suitable for fun game play with humans [19].
- Hamsters' natural habitat are burrows that have many tunnels and one of their natural behaviors is to tunnel [33]. This feature is used to promote their attractive pleasure in the game play of our system.
- Hamsters have cheek pouches to store food. This is convenient for both humans and pets as they can collect their reward from the attractor in our system [33].

It is noted that such an interface is meant to enhance human–animal interaction by allowing humans to continue interacting with their pet hamsters even in a remote situation, and is not meant to replace conventional human–animal interaction such as touch and hugging. A study to show that Metazoa Ludens is beneficial to the hamsters based on Body Condition Scoring study (which is a rapid and accurate scientific method for assessing the health status of small animals including hamsters [38]) was conducted. In addition, a user survey was carried out to evaluate Metazoa Ludens system as a game, by breaking down the system using features as described by Csikszentmihalyi's Flow theory [9]. The reason for using this theory for our experimental testing of our human–animal play system is substantiated by the academic GameFlow model [34] which states the appropriateness of using the Flow theory to assess not just the optimal performance condition but using it to assess the enjoyment of a user of a game, the game in our case being the Metazoa Ludens system. These studies were carried out based on these strong, dependent theoretical models as mentioned above to assess Metazoa Ludens in terms of the positive benefits to the hamsters and as an enjoyable interface to the human owners.

We begin by discussing related works done for both human–animal interaction, remote interaction system and other mixed reality game systems. The design for the system is discussed, followed by a technical description of the system. We evaluate the system both with respect to the hamsters as well as from the users' points of view. Then the results are presented and discussed, and also how the results may guide further iterative development of the systems, interface hardware and applications. As this research is not aimed just at providing specific experimental results on the implemented research system, but is aimed as a wider lesson for human-to-animal interactive media, the lessons learned are extrapolated and detailed in this chapter as a framework in general for human-to-animal interaction systems.

4.3 Related Works

4.3.1 Human–Animal Interaction System

Current human–animal interaction between pet owners and their pets mostly involve simple games to the likes of fetch, or chasing squeaky rubber toys. A more established tool-based interaction used for training dogs known as clicker training [31] uses a click sound made just before a treat is given. Nonetheless, all these game plays with pets do not utilize sophisticated technology. However, using sophisticated technology may be useful for enriching gameplay between animals and humans as it could add on to the existing ways of interaction and offer enriching experience that high-tech devices such as video game systems (Nintendo, Xbox, Playstation) are capable of giving.

Poultry.Internet (see Chap. 5), on the other hand, is an interactive system developed for remote human–pet (chicken in this case) interactions through the Internet. Pet owners can pat their pet chicken while away in an office or business trips through the Internet via a pet jacket which the pet chicken is wearing. The Petting Zoo [36] works on a similar concept where people use telephone buttons to remotely control a mechanical arm to pet a rabbit. Audio and visual support also allows them to watch and speak to the rabbit. Similarly, Cat Toy [26] developed a device capable of allowing owners to play with their cats and feed them via the Internet while watching them through the device's webcam. Nevertheless, these systems only provide a one-way interaction, the animals have no way of interacting remotely with the humans.

Infiltrate [17] is a system which displays a virtual scene from the point of view of a fish of a tank with fishes. A fish is selected and a screen projecting a virtual scene of what the selected fish is seeing is displayed. Although this system remains true of the general interaction one has with fishes (that is, interaction is nothing more than an owner viewing a swimming display), it offers no form of interaction between the audience and the fishes or the display screen other than a simply viewing the tank through the fish eyes.

In SNIF [15], a team conceived a notion of 'petworking' and developed a dog collar that could record the pet's behavior, activity as well as relay information about other dogs in the near vicinity to the owner. It can alert the owner via collar tones whenever the pet's play friend is out on a walk, or when another unfriendly dog is around the corner. These 'dog profiles' can be later viewed via the Internet and the owners can also make human–human connection with each other. Like Cat Toy, however, this system only allows the dog owners to remotely view the activities of the dogs, but does not allow any interaction between the dogs and their owners remotely.

Recently, Netband [28] was developing an Internet-based system of rearing a chick. The chick lives in a real non-digitized environment, but is only visible via the Internet. Owners are to tend to their pets, such as feeding and cleaning waste via tele-robotic and sensor apparatus, using the Internet. This system, however, does not allow the owner to interact with the chick in a more emotional and intimate manner, and vice-versa. It purely functions as a remote means of 'rearing' the pet.

Alternative technically sophisticated works of human–animal interaction mostly involve non-living electronic/virtual pets like AIBO [14], Tamagotchis [3] and Furby [18] which have been created to augment the human–animal interaction process by making use of digital devices to give a more enriching experience. Other uses of such robotic pets have been developed like Sekiguchi [32] who introduced a robotic teddy bear for interpersonal communication and Druin [11] who proposed a robot animal that is capable of telling stories to children.

Nonetheless, such virtual/robotic pets are not alive, hence lacking in complex behaviors and interactivity (that make live pets so endearing) and thus are not able to live up to the pet-owner's expectations of a pet [18]. Behrens [3] pointed out that unlike a real pet, when Tamagotchis die, they are born again and again (so long as the batteries last) which can be confusing, especially for children. This would foster a negative psychology within the children which may eventually negatively affect the society [35]. For the studies done on a group of children owning a Furby, it was found that when the robotic pet eventually broke and the children realized that it was only a toy, they felt angry at being fooled, betrayed and taken in, having emotionally invested on a machine which they thought was alive [18], thereby showing that there still exists a difference in perception and expectation between living and robotic pet companions. In addition, even though it was found that robotic pets like AIBO are capable of providing the elderly with physiological, emotional and cognitive relief, the companionship is still not the same as that shared by humans and real pets [24]. Thus, there is a need to create a system that is capable of greatly enriching the interactivity between living animals and humans by using advanced interactive media technology.

4.3.2 Remote Interaction System

As mentioned previously, the advancement of the modern world has brought pet owners away from their homes, spending hours at work either in office or overseas business trips away from their pets. This uncovered the need to incorporate remote interactivity into a human–animal interaction system. Related remote interaction systems include Psybench [25], InTouch [6] and Denta Dentata [16]. Such systems describe a bidirectional way for remote interaction; nonetheless, these remote interaction systems only take human–human interactions into consideration without considering human–animal interactions.

Rover@Home [31] is a system using common Internet communication tools such as a webcam, microphones and speakers to allow communication to dogs over the Internet. Nonetheless, the system is developed for the purpose of creating autonomous online virtual characters. A need thereby arose to incorporate remote communication technology into a system which allows remote interaction between humans and their pets.

4.3.3 Mixed Reality System

There are many mixed reality games that allow remote/web players to interact with players participating in the game in a more physical and ubiquitous manner. For example, Can You See Me Now? [4] whereby physical players chase remote avatars of web players, Human Pacman [7] whereby players don the roles of both Pacman and Ghost and play the traditional video game of Pacman in a real physical environment with augmented reality display. Such mixed reality games not only allow remote interaction between players but they open up a new genre of gaming whereby the traditional electronic games are taken out of the computer and players no longer sit in front of the computer to play games. Nevertheless, such mixed reality games only address human–human interactions.

In Cricket-Controlled Pacman [39], a human player may play the traditional computer game of Pacman with real live crickets, in a kind of mixed reality game. The crickets play the role of Ghosts and run in a real maze, while the human plays the role of Pacman and controls Pacman on a virtual game screen. Nevertheless, in the real maze the ground vibrates with the aid of motors. This agitates the crickets and causes them to flee. This is done to ensure that the crickets, as Ghosts in the game, are constantly moving to "chase after" Pacman to allow a more enjoyable game play for the human. A negative motivation (fear from the vibration) is employed throughout the game to the crickets to ensure an enjoyable game play for the human. The crickets are merely acting our of fear and moving in random directions.

Building upon all these pet–human interactive systems, Metazoa Ludens extends and augments them by allowing bidirectional interaction between pet owners and their pet hamsters via playing computer games (locally or remotely). It should be noted that Metazoa Ludens is an interface meant for the benefits of the small animals (like hamsters) as well as in promotion of the awareness of digital human–animal interaction. Positive motivation is employed throughout the game such that the hamsters perform the game play willingly, and not out of fear or agitation. In addition, the game play ensures healthy exercise to the hamsters which is beneficial for the well being of the pets.

4.4 Metazoa Ludens: Fundamental Design

With a human–animal mixed reality remote interaction gaming system in mind, designs and conceptual outlines are drawn. These result in an iterative development which forms the eventual system design. For better interaction between users (humans and hamsters) and the system, possible user scenarios are given. These are for a better understanding of the users' interaction needs, and hence are given consideration in the system's interface design.

4.4.1 Remote Interaction

Marie finally gets back to her hotel room in Tokyo after a long day of business meetings. She turns on her Metazoa Ludens system and is immediately connected to her beloved pet hamsters, thousands of miles away in Los Angeles. She can carry on playing games with them as if she was back home.

Metazoa Ludens aims to provide easy remote connectivity between humans and their pet hamsters. Owners can get connected to their hamsters via Metazoa Ludens using existing Internet infrastructure which is available globally. This is to ensure owners are still connected to their hamsters even when they are physically apart.

4.4.2 Pet's Choice

Mid-afternoon, Fluffy, feels it is time to play Metazoa Ludens with her mistress, Mandy. She chooses to start the game with Mandy and moves into the game play area from her cage.

It is important that the hamsters are given a choice to play the game. The interface for the hamster thus should include a way for it to choose. One way for it to communicate its choice is to create a tunnel, from its cage to the structure for game play. It is then able to "select" whether to play or not by moving to and fro between the cage and the structure through the tunnel (as its interaction interface).

4.4.3 Pet Interface

After one month of using Metazoa Ludens, Billy noticed his pet hamster is less obese and more active than before. His hamster is also more willing to leave the cage to play Metazoa Ludens with him.

Metazoa Ludens should not only benefit humans but also hamsters. One way to incorporate benefits to the hamsters is through the way they interact with the system.

By incorporating mild exercise for them, the system will become beneficial for the hamsters' health and well being. Regular exercises will prevent the hamsters from being obese and thereby reduce the possibilities of obesity-related diseases.

Examining possible exercises for hamsters, the idea of using the running wheel (most common for hamsters) is discarded as it is known to cause chronic stress and significant hypertrophy of the heart in hamsters and can result in injuries whenever the hamsters' feet get stuck in the wheel [22]. Running which comes most naturally to the hamsters is thus selected. This suggests a running area for the hamsters since they will be interacting with the system through running. The running area thus becomes the primary interface for the hamsters. In comparison, the standardized running wheel size is about 105 mm in diameter; the standardized commercial cage is about 215 mm by 270 mm; the running area of Metazoa Ludens is 860 mm by 860 mm. Thus Metazoa Ludens gives a large free running space for the hamsters, in which they may prefer over their smaller cages and running wheels as they love to run around large areas [23].

A source of positive motivation for the hamsters to run will be required to enforce a positive feeling for them to play the game. An attractor which could naturally attract the hamsters to it (like a bee to a flower) is used to entice the hamsters into running. As hamsters are known to be food gatherers (rather than predators), it is not in their nature to run after food. Hamsters generally love to explore tunnels [29] as that is where they normally store their food resources [23]. A mechanical arm holding a small tunnel is thus created to give a positive motivation for the hamsters during the game play. Humans will have control of the mechanical arm via the Internet. This forms the interface enabling the interaction between the hamsters and humans through the system.

4.5 System Description

With the system interface design as described above with consideration of the humans' and the hamsters' needs. An overview of the overall system (see Fig. 4.1) is given next, followed by technical details of the system.

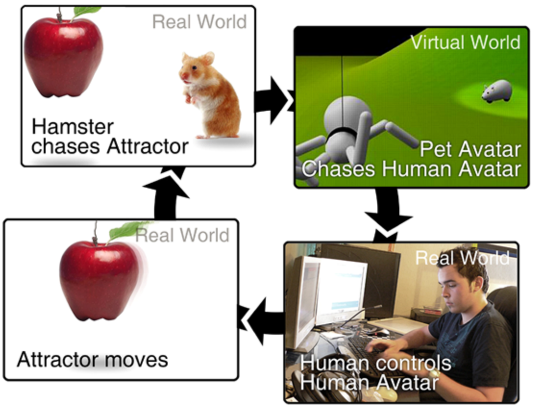

Fig. 4.1 System overview

4.5.1 System Overview

In the real world within the big running space of the system, a hamster chases after a physical movable arm on a moldable surface area. The movement of the hamster is then translated into the movement of a pet avatar in the virtual gaming space which is shared by the human. The human controls the movement of a human avatar in the virtual gaming world, which is actually controlling the movement of the physical attractor in the real world. Thus, this loop enables the merging of two realities, both human's virtual reality and the animal's physical reality, either locally or remotely via Metazoa Ludens system.

Inside the structure, a camera is placed at the top of the structure for tracking the hamsters' movements on a mechanically driven arm that makes up the movable attractor. The surface which the pet hamsters scamper upon is a highly moldable latex sheet molded by sixteen actuators (electric motor driven) placed directly beneath them.

The system/game engine is basically made up of three subsystems. Firstly, a camera subsystem which will take care of the camera tracking of the hamster. Secondly, a hardware subsystem to (a) send signals to the stepper motors that will in turn control the actuators and the three degree of freedom mechanical robotic arm, and (b) communicate to the client using the Internet. Lastly, there is a game subsystem which processes the 3D real-time graphics of the virtual gaming world as well as the game play. The structure will house the camera subsystem as well as the hardware subsystem in two workstations named the camera server and system server, respectively, while the equipment that the owner is using (be it a desktop at home or a laptop in a hotel room) holds the game subsystem in another computer named the client. The basic functioning of these three subsystems is to facilitate remote communication between the structure and the client over the Internet.

4.5.2 Camera and Tracking Subsystem

For Metazoa Ludens, a color tracking system is required to obtain the positions of the hamsters. In addition to that, the hamsters' spatial coordinates must also be available at every point in time. To do so, the system has to be capable of acquiring an image of the playing field at any one point in time and identify the hamsters, matching the hamster profiles to the different hamsters, then matching these profiles to their respective coordinates and returning them to the program.

The cameras are placed at a height of approximately 600 mm from the floor of the tank, and each has to capture the entire floor at once, measuring an area of 860 by 860 mm. This being the case, the acquired image has to contain much more than the floor within its 640 by 480 pixels. Thus, after acquiring the image, the image has to be cropped first by pre-defining the dimensions for the final image and discarding regions out of the range. The input image is then thresholded against the background color (obtained during initialization of the program). For the purpose of Metazoa Ludens, black was chosen as the background color of the floor as few hamsters are entirely black, with the exception of the black Syrian hamster.

The tracking system consists of two video cameras which are mounted on top of the unit looking down, in order to cover the whole area inside which the pets can move. The tracking process can find the position of each individual pet in the area, which is then used as an input for the game engine. As the pets can only move on an essentially flat surface, and the camera is mounted on top and is looking down, the problem can be tackled as a 2D tracking problem. The background of the tracking input is a black fabric which allows the use of thresholding techniques for segmentation [19]. For the purpose of Metazoa Ludens, black was chosen as the background color of the floor as few hamsters are entirely black, with the exception of the black Syrian hamster. Furthermore, the setup ensures that occlusion, which is a big problem in other applications like people-tracking, is not an issue.

The tracking application is written using OpenCV.[1] Operation of the system OpenCV's callback function provides the frame image to the application. It is cloned to a separate variable and processed to identify the hamsters. Using the standard deviation and the average color of the background, anything distinguishable is identified as a blob. These blobs are then re-processed to evaluate the average area and the length of the major and minor axes which are compared to those of the hamster's parameters to identify the blob of the hamster. A separate test application was written to collect parameters (area, lengths of the major and minor axes) of different hamsters. The application allows the hamster to move freely inside the unit and collect data. After a few minutes, the application provides an average estimation of all the necessary parameters. These parameters are used by the tracking application to identify the hamsters. Finally, the coordinates of the identified hamster blob is transmitted to the game as the hamster avatar's coordinates. The tracking algorithm is summarized in Fig. 4.2. Although this method is simple, it is computationally cheap and therefore suitable for a real-time tracking. It has one major drawback, namely, it works if only one hamster is present because multiple objects influence the tracker altogether.

4.5.2.1 Histogram Based Tracking

By using an optional histogram based tracking application, the system can detect individual hamsters. This would enable the game to be played with more than one hamster. Histogram descriptors are based on the distribution of values which are part of the region. To build a histogram, the range of values is segmented into a finite number of sub-ranges. Every input value is sampled, and fit into one of the sub-ranges. The bin which corresponds to the sub-range is then incremented by one. Therefore, a histogram shows the distribution of values in a range. The resolution of the histogram depends on the number of bins which are used. Histogram descriptors do not model the spatial layout of the pixels in the region, but use the frequency of values to describe the region. Histogram descriptors can be derived from gray values as well as from color channels (R, G, B) of a color image. The RGB color model describes the color of a pixel by the intensity of red, green and blue light. Unfortu-

[1] http://opencv.willowgarage.com/wiki/.

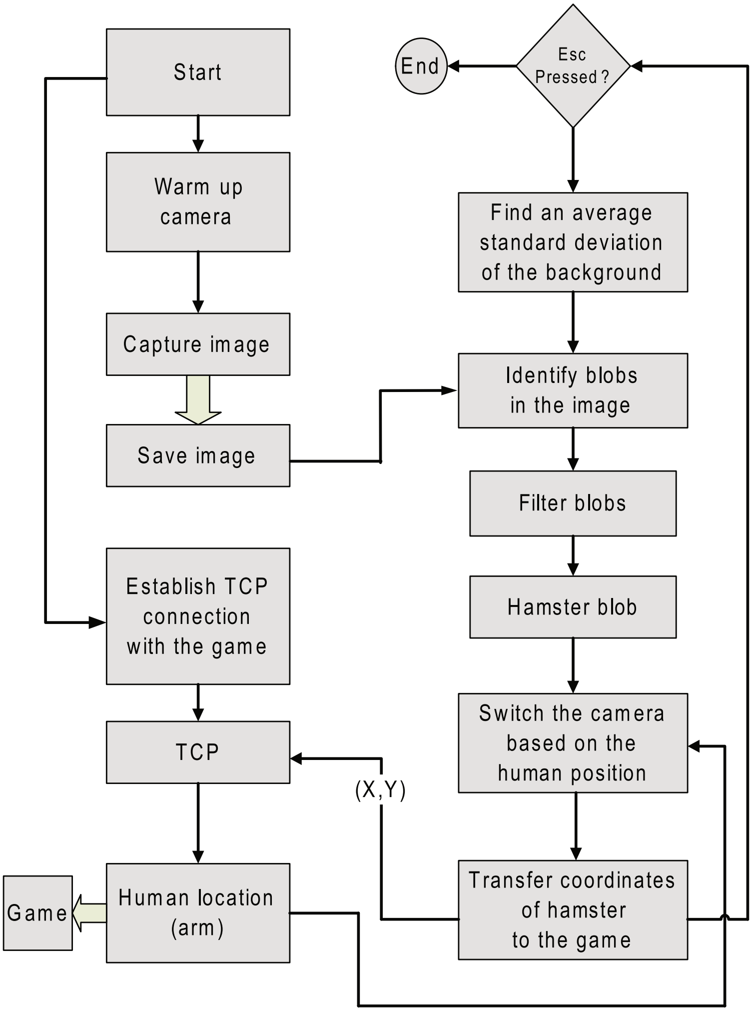

Fig. 4.2 Hamster tracking algorithm

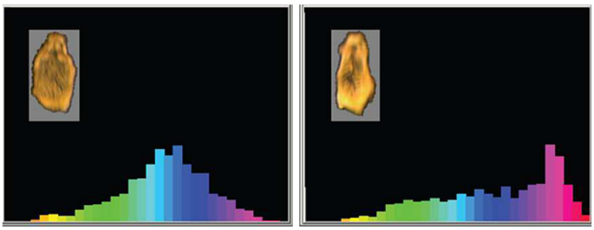

Fig. 4.3 Histogram descriptor: the image shows the color images of two hamsters as well as the corresponding histograms of the luminance value in HSL color space

nately, this representation mixes the brightness and the hue of a color into the RGB values. Therefore, it can be helpful to convert the image into another color space, for example HSL, which describes a pixel by its hue, saturation and luminance value, if color information should be used as a descriptor [20]. Similar to previously described method, a test application was written to construct histograms for individual hamsters (Fig. 4.3). The hamster is allowed to move freely inside the unit, while the histogram is computed for every frame and accumulated to a mean histogram which describes the specific hamster. This process is done for every hamster, and it is stored as a file. This file is loaded when the histogram based tracking application starts. This application identifies blobs someway as the basic tracking application. Then it constructs histograms for each blob and carries out a histogram matching using the loaded histograms to identify individual hamsters from the blobs.

Orientation of the hamster is calculated by tracking their previous coordinates and comparing it with their current coordinates. A vector is formed using these two sets of coordinates and the angle between the previous orientation of the hamster with this vector gives the angle for turning the pet avatar in the virtual world.

4.5.3 Hardware Subsystem

The hardware portion of the system (see Fig. 4.4) consists of the server computer transmitting commands to the “Master” units, which then decode the commands and relay them out to the “Slave” units that are connected to 16 actuators (see Fig. 4.5) used to mold the latex surface and robotic arm used to move the attractor. Each Master is connected to one or more Slaves. There is full bi-directional transmission capability between the Master units and the server computer, and between the Slave units and the Master units. Finally, the Slave units order control the actual power electrical signals required to move the actuators up and down as required.

Data transmitted to the Master Unit are then transmitted to the Slave Units each of which controls the actions of a single actuator unit. For communications between the Master Unit and the Slave Units, the I2C protocol is used. The Slave Unit interprets the digital commands issued from the server computer and converts them into the power electronic signals required to cause motors of the actuators and the robotic arm to turn. When the motor turns, it will turn the lead screw of the actuator attached to the motor which in turn moves the actuators vertically up and down. The same mechanism is used for the robotic arm which moves horizontally left and right accordingly.

4.5.4 Moldable Latex Surface

A moldable latex sheet is used for the running area’s surface. This enables the mechanical actuators below the sheet to be able to mold the shape of the surface (see Fig. 4.5) in accordance to the virtual terrain of the gaming world in real time (see Fig. 4.6).

Latex is used as the elasticity and the strength of the material allows it to be stretched while being strong enough to withhold the weight of running hamsters.

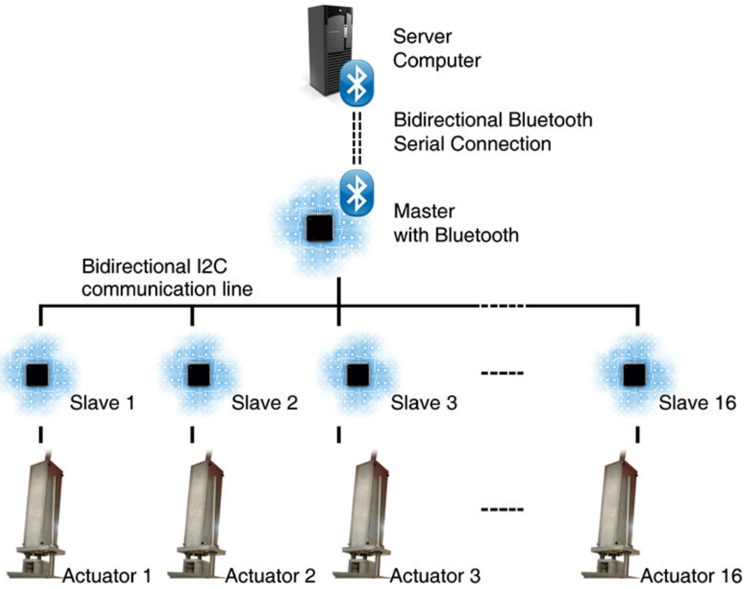

Fig. 4.4 Hardware overview

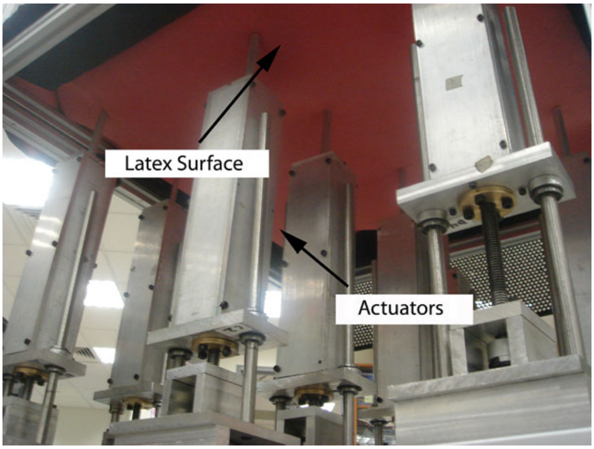

Fig. 4.5 Actuators and latex surface

4.5.5 Game Subsystem

An overview of the game engine is given in Fig. 4.7. Functionalities shown in Fig. 4.7 will be encapsulated as objects for the game and rendered as 3D graphics onto the human user's screen (see Fig. 4.8). Like most game engines, the basic functionalities like camera view, rendering of objects and such will be included.

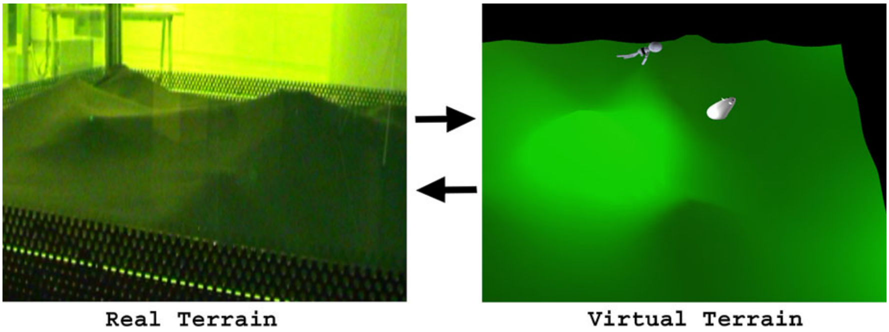

Fig. 4.6 Terrain mapping between the physical and virtual spaces

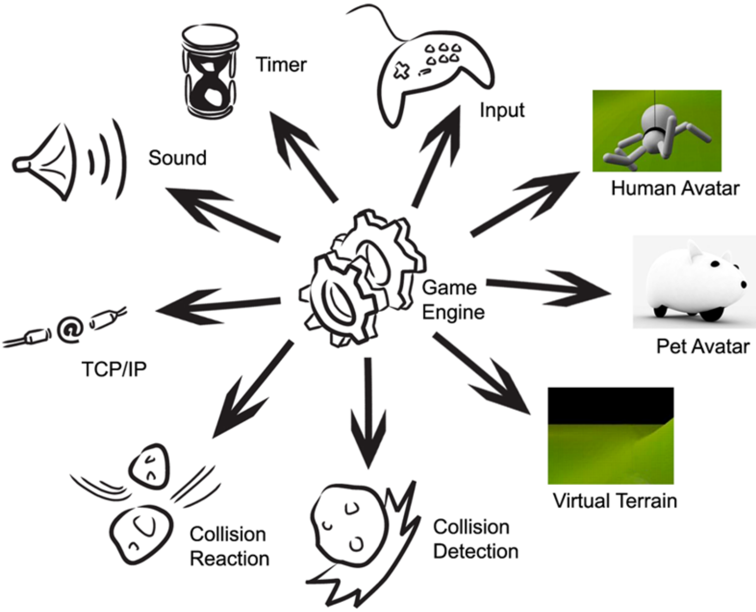

Fig. 4.7 Game subsystem architecture

Human Avatar The main character of the game is the human avatar which is basically a 3D object (a humanoid figurine hanging in the mid air) rendered onto the game terrain and controlled by the human. Movements of the human avatar correspond to the physical three degree of freedom robotic arm in the hamster play arena. Every time the human avatar comes into contact with the pet avatar she will lose its health points. This implies the need for collision detection and reaction to take this into consideration.

Pet Avatar This is a virtual representation of the pet hamster in the physical hamster arena. It is a 3D object (of a giant hamster) who is controlled by the hamster through the coordinates obtained from the camera.

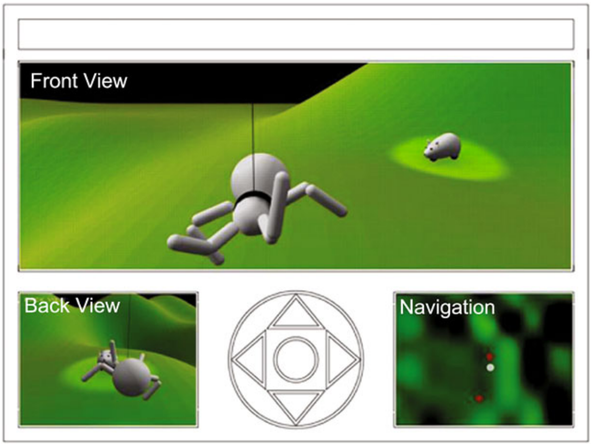

Fig. 4.8 Virtual world game interface showing hamster avatar chasing human avatar

Virtual Terrain This is a virtual representation of the real elastic moldable terrain from the structure. This implies a virtual terrain which may be molded in many ways like a sheet of elastic surface. As the surface of the real terrain is determined by the actuators' displacement, the contours of the virtual terrain will take in its variable from the various actuators' displacements. This will be done in either a maximum or minimum elliptic paraboloid with the actuators' displacements as its turning points so as to create a realistic representative of the contours of the real terrain.

Collision Detection and Collision Reaction Various interactions between the 3D objects (like human avatar and pet avatars) require collision detection as well as different collision reactions to handle specific situations. For example, when the human avatar collides with the pet avatar, he will lose health points.

4.5.6 User Game Play Experience

We will now describe a typical usage scenario of our system. While furry hamsters run through the tunnel and into the Metazoa Ludens' structure, it signifies the start of the gameplay between the hamsters and their human pets. The pet owner gets ready in front of her computer (either at home with the pets or remotely over the Internet) with a virtual world on her screen (see Fig. 4.9) while the hamsters scamper across the moldable latex surface with the mechanical attractor ready for action.

At the game start, the pet owner moves a human avatar, tangling on a string in the virtual world and flies the human avatar across the changing virtual terrain. This controls the mechanical attractor within the tank which then moves in correspondence to the human avatar. The latex surface changes in surface contour as molded by the actuators below, this in turn corresponds to the changing contours of the virtual terrain accordingly.

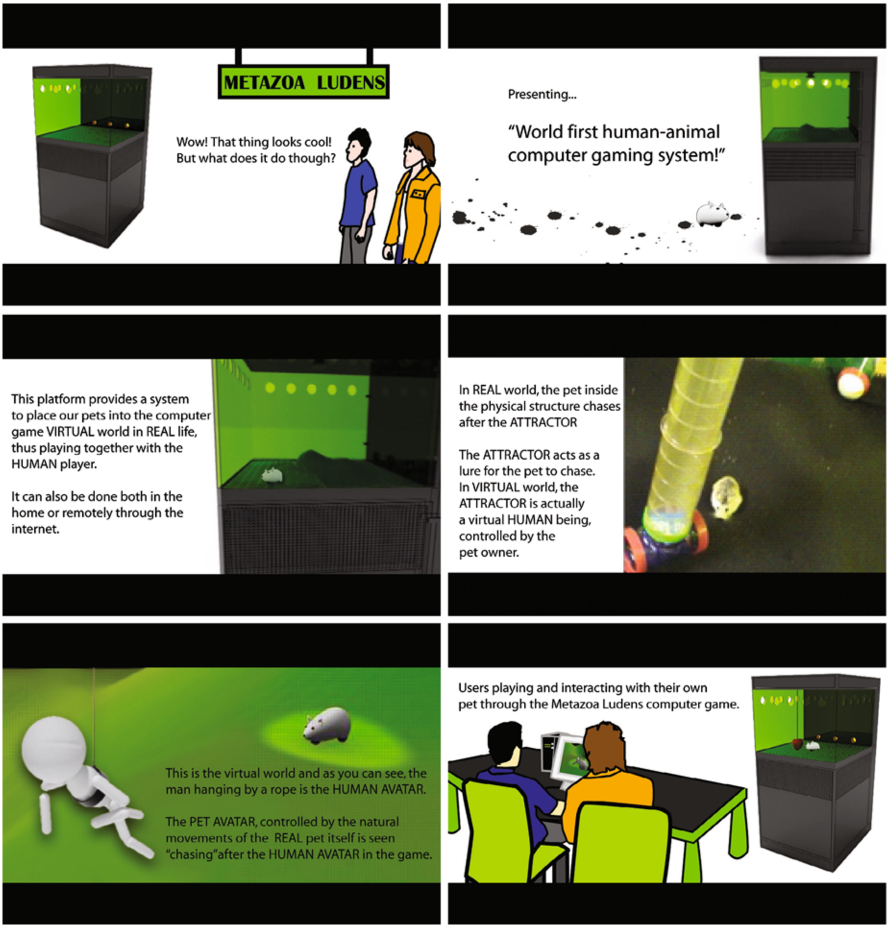

Fig. 4.9 Users' experience

The furry hamsters chase after the mechanical attractor as driven by the pet owner. The movements of the hamsters are tracked by the cameras at the top of the structure, which thus moves the pet avatar in the virtual world, mapping the position of the real hamsters chasing after the mechanical attractor (which in turn chases after the human avatar in the game).

The basic game concept behind Metazoa Ludens game is a predator and prey chase game; however, the roles are reversed in the sense that the bigger human is now being chased by the physically smaller hamsters in the virtual world (pet avatar chases after human avatar). A general strategy of the pet owner is to try her best to keep moving her human avatar so as not to be caught up by the pet avatar (hamster), which will then deplete the human avatar's health points. As the game progresses, the human avatar will eventually escape the clutches of the pet avatar within a certain time or finally get caught up by her own pet hamsters to the point of zero health points before the game rounds up.

The game revolves around a simple concept of chase and run; nevertheless, playing with your favorite pet hamster over the digital screen and being chased by them adds more intrinsic value to the game play. While not trying to replace conventional human–pet interaction, this way of playing a game with the aid of a digital system (either locally or remotely) definitely adds more variety to the way a pet owner may play with their small pets and maybe for once experience the thrill of being chased by their small pets (which is not possible in the physical world due to the great dissimilarity in size).

4.6 Evaluation, Results and Discussion

4.6.1 Study 1: Health Benefits to the Hamsters

A trial test was carried out to assess the benefits of the system through regular exercise to the hamsters. In assessing the health of small pets like hamsters and maintaining their natural lifespan, it is best to have a common descriptive method among scientists and veterinarians. Body Condition Scoring (BCS) is an accurate and useful tool used for the evaluation of overall health condition of animals like mice and hamsters. Unlike impractical techniques like obtaining body weights and temperatures which can be time-consuming and tedious, BCS techniques are more practical and rapid [38].

Evaluations on individual hamsters are done at least once a week to monitor the hamster closely. The body condition of the hamster is given a score based on a scale of 1 to 5 as follows:

5 The hamster is obese; its bones cannot be felt at all.
4 The hamster is well-fleshed; its bones are barely felt.
3 The hamster is in optimal condition; its bones are palpable but not prominent.
2 The hamster is getting thinner; its bones are prominent.
1 Advanced muscle wasting, fat deposits are gone, bones are very prominent. Euthanasia is mandatory.

As hamsters playing in Metazoa Ludens are given exercises, it is hypothesized that hamsters playing in Metazoa Ludens will have a BCS of closer to 3 after the duration of the study.

Subjects Subjects were hamsters, *Phodopus roborovskii*, belonging to a local group of hamster lovers' community whose owners took part in the study (see Study 3) together with their pet hamsters to promote the use of technologically aided human–animal interaction. Subjects were between 1 and 2 years of age and were viral antibody free and parasite free. These were monitored by examining on skin scrapings, fecal flotation samples and anal tape impressions. For uniformity purpose, the same diets (seeds) and filtered water were given to the subjects throughout the duration of the study. The cages were allocated in a room with controlled lighting system and optimal temperature and humidity [23].

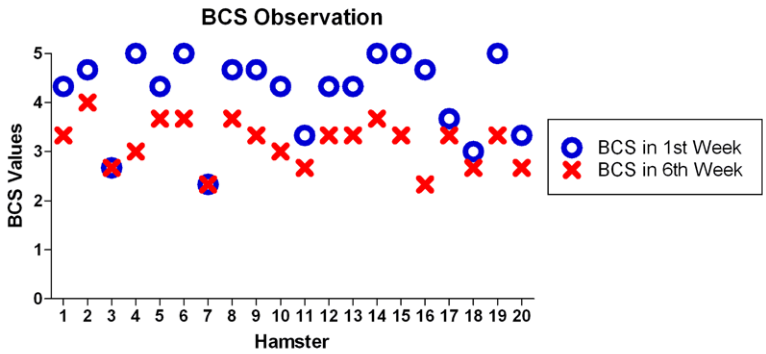

Fig. 4.10 BCS results of the hamsters over 6 weeks

Procedure All hamsters had their BCS taken at the start of the 1st week of the experiment by three different observers and the mean BCS was taken. BCS was assessed by placing the hamster on a flat surface. The base of the tail was held with the thumb and index finger of one hand. The scoring of the degree of flesh and fat covered was done either by running the little finger of the same hand over the sacroiliac area or by palpating the sacroiliac area with the fingers of the other hand [38].

For 6 weeks, the metabolizable energy requirement (MER) [13] from each hamster was calculated daily, and the amount of food they were given each day was in accordance to the MER of each individual hamster. This was to ensure each hamster was given just the right amount of food and to prevent a situation whereby the hamsters were to lose weight due to undernourishment or to become obese due to overfeeding.

The hamsters were allowed to play Metazoa Ludens for an hour each on every weekday for the period of 6 weeks. At the end of the 6th week their mean BCSs were taken again.

Statistical Analysis To compare ordinal data (discrete scoring of BCS) between two time points, we used the Wilcoxon signed-rank test for paired data. A group size of 20 subjects was used as when the sample size, n, is more than 15, n is considered large and the distribution tends to a Normal distribution [40]. All statistical tests were two-tailed, with statistical significance at 0.05. Data are expressed as means unless otherwise specified.

Results Of the 24 hamster owners and their pet hamsters screened, 20 (about 83%) subjects were enrolled in the study (3 were not interested, 1 did not return for a follow-up). The final study group consisted of 9 female hamsters and 11 male hamsters. The results are shown in Fig. 4.10.

By using Wilcoxon signed-rank test, Metazoa Ludens was found to be able to change the BCS of the subject hamsters over the study period ($z = -3.8230$, $p = 0.0006$). Further statistical analysis of the mean BCS of the hamsters in the 6th week using Wilcoxon signed-rank test showed that the mean BCS of hamsters after 6 weeks of using Metazoa Ludens tends towards 3 ($z = -1.4154$, $p = 0.1586$), which is the optimal BCS score for hamsters.

Hence it can be concluded that after 6 weeks of playing Metazoa Ludens, the hamsters are getting healthier and their body condition tends to optimal.

4.6.2 Study 2: Pets' Choice

Besides studying the health benefits of hamsters, a separate study was carried out to measure the motivation of the hamsters to play Metazoa Ludens. Study 2 was carried out after Study 1 as both studies were rather similar, and we did not want an interference of results. In this study, the method of Duncan [12] was adapted to assess the strength of preference of the hamsters towards Metazoa Ludens.

Subjects Subjects used were the same subjects used in Study 1 with all experimental conditions remaining unchanged.

Procedure All hamsters were placed in their individual cages separated from the Metazoa Ludens structure. For 2 hours a day, each hamster's cage would be linked to the tunnel connecting to Metazoa Ludens (described in Scenario 2 previously). The hamster were left to explore the structure without the game play for about 1.5 hours. This was to act as a control against the hamster coming into the structure out of inquisitiveness rather than a desire to play the game. Once 1.5 hours was up, a whistle was blown to signify the start of the Metazoa Ludens game. The hamster could chose to stay or leave the structure through the tunnel at this point of time. After 1.5 hours of exploring the big structure, the curiosity should have worn off and the hamsters would readily return to the safety of their homes (or run for cover) should they feel uncomfortable even if they were running in a big field [38]. The number of times the hamsters remained in the Metazoa Ludens structure (or enter the structure via the tunnel should they be in the cage at the whistle blow) for game play was noted.

The study was carried out for 4 weeks, and the mean percentage for the number of times each hamster chose to play Metazoa Ludens in the 1st week was compared to that in the 4th week. Based on the design of the pet interface which is towards the preference of the hamsters (see Scenario 3), we hypothesized that after 4 weeks the mean number of times for the hamsters to choose to play Metazoa Ludens were to increase, that is, the hamsters' preference for Metazoa Ludens were to increase.

Statistical Analysis Like Study 1, Wilcoxon signed-rank test was, used and all other statistical assumptions and conditions remained unchanged unless otherwise stated.

Results The results are given in Fig. 4.11. By using the single-tailed Wilcoxon signed-rank test, it was shown that the mean number of times taken for the hamsters to play the game per day increased over the study period ($z = 3.9199$, p more than 1.0000). With the two-tailed Wilcoxon signed-rank test, it was shown that this increase was by 6 times per day out of the 10 possible given chances ($z = 0.7467$, $p = 1.5468$), that is, 60% increase.

As it is shown that the hamsters increasingly choose to play Metazoa Ludens during the study period, we conclude that the hamsters have a positive desire to play Metazoa Ludens.

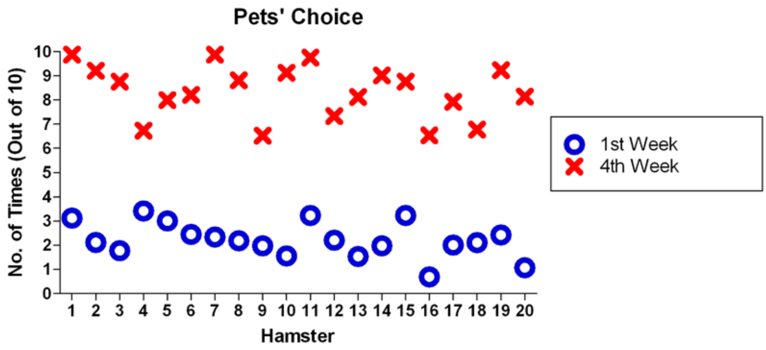

Fig. 4.11 Results of Pets' Choice over 4 weeks

4.6.3 Study 3: Users' Enjoyment Based on Flow

For the users, a survey was carried out to evaluate Metazoa Ludens system as a game. The game flow of the system was then broken down using features as described by Csikszentmihalyi's Flow theory [9] to evaluate the users' enjoyment of the game. Metazoa Ludens game flow was broken down as follows:

- *Concentration.* Concentration on the game is needed, and players should be able to concentrate on the game.
- *Challenge.* The game should contain challenges that match the player's skill level.
- *Player Skills.* Player skill development and mastery should be supported in the game.
- *Control.* Player should be able to feel in control of his actions in the game.
- *Clear Goals.* Clear defined goals should be given to the players at appropriate times.
- *Feedback.* Appropriate feedback from the game at appropriate times should be given.
- *Connection.* Players should feel deeply connected to the game and with little/no effort.
- *Social Interaction.* The game should support social interaction as well as create opportunities for it.

The original set of questions for the Flow model has been created for a generic task (like surfing the Internet), therefore some questions have been modified to adapt to the Metazoa Ludens environment. In addition, questions related to human–animal interaction are added in as well. Table 4.1 illustrates the questions and the corresponding criterion and elements in the Flow model.

Subjects Subjects were recruited from a local group of hamster lovers' community. There were 20 subjects randomly selected with an average age of 25.4 years. Gender was 55% male and 45% female. All subjects completed written informed consents before inclusion in the study.

Table 4.1 User evaluation questions based on the Flow model

Element	Question
Concentration	1) Did the game grab your attention and maintain your focus?
	2) Can you concentrate on the tasks at hand in the game?
Challenge	3) Do the game skills needed match yours?
	4) Do you think the game provides different levels of challenge for different players?
	5) As the game progresses, does it become more challenging?
Player Skills	6) Are you able to play the game without spending too much time with the instructions?
	7) Is learning how to play the game fun?
Control	8) Do you feel in control of your character in the game?
	9) Do you feel in control of the game shell (starting, stopping, saving, etc.)?
Clear Goals	10) Is the objective of the game clear and presented early enough?
	11) Are the intermediate game goals clear and presented at appropriate times?
Feedback	12) Do you have a clear picture of your progress towards the game goals at any point in time?
	13) Does the game give you immediate feedback of your actions?
	14) Do you always know the number of your health points and time remaining?
Connection	15) During game play are you less aware of what is happening physically around you?
	16) Are you aware of the passing time during game play?
	17) Do you feel emotionally involved in the game?
Social Interaction	18) Do you feel the competition against the pets and other players (if any)?
	19) Does the game support social communities (for both human players and pets) inside and outside the game?
Human–Animal Interaction	20) Are you aware that you are playing with a hamster during game play?
	21) Do you feel more connected to the pets after game play?

Procedure The survey was conducted on the first time users of Metazoa Ludens right after game play. Data collected from the survey are expressed as means and standard deviations, unless otherwise specified.

Results Results of the survey (in %) are given in Table 4.2. Of all the elements explored with this survey, most of them performed positively in the survey; as for all questions posed, more than 50% selected the favorable choice. Nevertheless, it is noted that the Social Interaction element did not score as well as the rest.

Table 4.2 Results of the survey (in %)

Qn	Options				
	Yes, very	Yes	Fairly	Not really	No
1	75	25	0	0	0
2	70	10	20	0	0
3	65	20	15	0	0
4	70	30	0	0	0
5	60	20	20	0	0
6	95	5	0	0	0
7	85	15	0	0	0
8	95	5	0	0	0
9	65	20	10	5	0
10	95	5	0	0	0
11	70	5	20	5	0
12	65	15	20	0	0
13	65	15	15	5	0
14	85	5	10	0	0
15	95	5	0	0	0
16	60	40	0	0	0
17	40	50	10	40	50
18	15	70	10	5	0
19	15	55	20	10	0
20	60	10	15	15	0
21	65	30	5	0	0

For Social Interaction, the majority agreed that they do feel the presence of social interaction at work instead of feeling "greatly" the presence of social interaction. However, considering that the players were new to the game and had to cope with getting used to the controls and game play in real-time, having felt the presence of social interaction instead of feeling "greatly" for it should be considered a positive result. A possible way to improve Social Interaction further would be to include voice and video feature which will then allow players to "speak" to the hamsters over the Internet via a microphone so that the hamsters may be able to recognize their owners' voices and also to give live video feed of the hamster back to the owners' computer to allow them to "see" their pets.

Generally, it can be concluded from the above results that the goals (from Flow metrics) are effectively implemented.

4.7 Framework for Human–Animal Interaction System

This research is not only aimed at providing a detailed experimental verification and results for human–animal mixed reality interactive play, but also at providing lessons of wide applicability for human–animal interactive media. A possible framework or a set of design guidelines used to describe human–animal interaction system and the interactions involved may be developed from the setup of Metazoa Ludens. This will allow future human–animal interaction systems to be developed based on the given framework and/or design guidelines. Interactions design between a human and an animal can also be based on the given framework/guidelines. The benefits of this would be a faster and better designed system since the framework can provide possible insights for a new human–animal interaction system to be built. Knowledge learned from Metazoa Ludens (in terms of the design of the system as well as interactions) can thus be reused and applied onto these new systems.

There has been extensive literature and research done on the design principles for human–computer interaction systems [10], hence the framework's emphasis will be on the animal/pet instead. Five design dimensions which are to be thought of as design choices (details discussed below) for a human–animal interaction system are presented. These arise from thinking about the essentials needed for keeping and interacting with a pet at home. The dimensions are:

- *Habitual design*. The area of interaction should be safe, comfortable and suitable for the animal. For example, while it is possible to play a game with your pet dog in a swimming pool, it might be better and safer to play in an open field. Choices available for this dimension are: Native, where the environment used is where the animal normally resides; Recreated, where the environment is not where the animal normally can be found but yet not unsuitable for the animal to stay in; Unsuitable, where the environment is not suitable for the animal.
- *Ease of use*. The way to interact with the system should come naturally to the animal since it is not an easy task to teach the animal to, for example, use a keyboard or mouse as input. Natural behavior of animals in focus thus need to be studied and modeled as means of input. For example, asking your pet dog to fetch a ball may yield better results than asking it to climb a tree. Choices available for this dimension are: Instinctive, where the actions required from the animal are instinctive to what the animal normally does; Learned, where the animal requires a certain learning process to perform the tasks required; Unsuitable, where the actions required are unsuitable to be performed by the animal.
- *Interactivity*. While it is fun to watch your dog chase after a ball, it would be better if you could throw the ball while your dog runs after it. It thus becomes a consideration to allow interactivity in a human–animal interactive system. Choices available for this dimension are: None, where there is no interactivity between the human and the animal; One-way, where interaction is only one-way; Two-way, where interaction is two-way.
- *Pet's choice*. It could be fun to always ask your dog to chase after your thrown ball, but there may be days when your dog would prefer a nap in the living room. Therefore, while allowing you to play with your pets, such a human–animal interaction system should consider giving the animals a choice for interactivity. Choices available for this dimension are: Yes, where animals are given the choice to use the system; No, where animals are not given the choice to use the system.

- *Animal's gratification*. While it could be fun to play fetch ball with your dog, it should be ensured that your dog is enjoying it as well as gaining from the benefits of exercising (running after the ball). There thus should be some form of gratification (be it health benefits or entertainment) for the animal in using the system, else it would be just a case of making the animal perform certain tasks for the entertainment of the human. Choices available for this dimension are: Gratified, where the animals are given some benefits or gratification from using the system; Neutral, where animals are given neither gratification nor dissatisfaction from using the system; Dissatisfied, where animals gets negative gratification from using the system.

Nine existing human–animal interaction systems are ranked upon the five axes, each axis having been divided into five bands from low to high. The systems are ranked accordingly to the information obtained from published conferences and journal papers as well as official websites of the systems. These nine systems chosen are not intended to be an exhaustive list of all human–animal interaction systems since, while having an exhaustive list gives completeness, it may not be required for the development of a human–animal interaction system framework.

The research systems which are included are: Rover@Home [31], Cat Toy [26], Poultry.Internet [24], Pet Zoo [36], Infiltrate [17], SNIF [15], Netband [28], Crickets Pacman [39], and Metazoa Ludens.

Figure 4.12 shows the five dimensions for the analysis with each of the systems placed into a group along with the others. Colored lines trace the rankings of systems on each axis while each axis has values described below. Based on the clustering of systems, four design patterns for a human–animal interaction system (after pattern language for architectural studies [1]) are thus obtained. These four archetypes are: *Restricted Interface, Discretionary Contact, Digital Live Display,* and *Interactive Connection*.

Restricted Interface describes Rover@home and Cat Toy. Such systems score fairly well in four of the dimensions except for Interactivity. Interaction is mostly one-way, from the human to the animal, the animal has no means to interact directly with the human. Such systems are mostly intended to have a restricted one-way interface focusing on the human's interaction with the animal.

Discretionary Contact describes Poultry.Internet and Pet Zoo. Such systems score fairly well in four of the dimensions except for Pet's Choice. Despite for the animals having little choice in participating in this interaction, it is noted that gratification or benefits for the animal are high. In the case of Poultry.Internet, while the chicken has no choice as to be patted by the human, being patted does do good for the chicken's general well being. Such systems are mostly intended for the human to contact the animal (for its own benefits and gratification) at the human's discretion.

Digital Live Display describes Infiltrate, Cricket Pacman, SNIF, and Netband. Such systems score very well in Habitual Design and Ease of Use, while scoring very low for the remaining dimensions. These systems generally focus on being a means of digital live display for the human with little emphasis on the animal's choice to interact, their interaction with the human and their gratification from such systems.

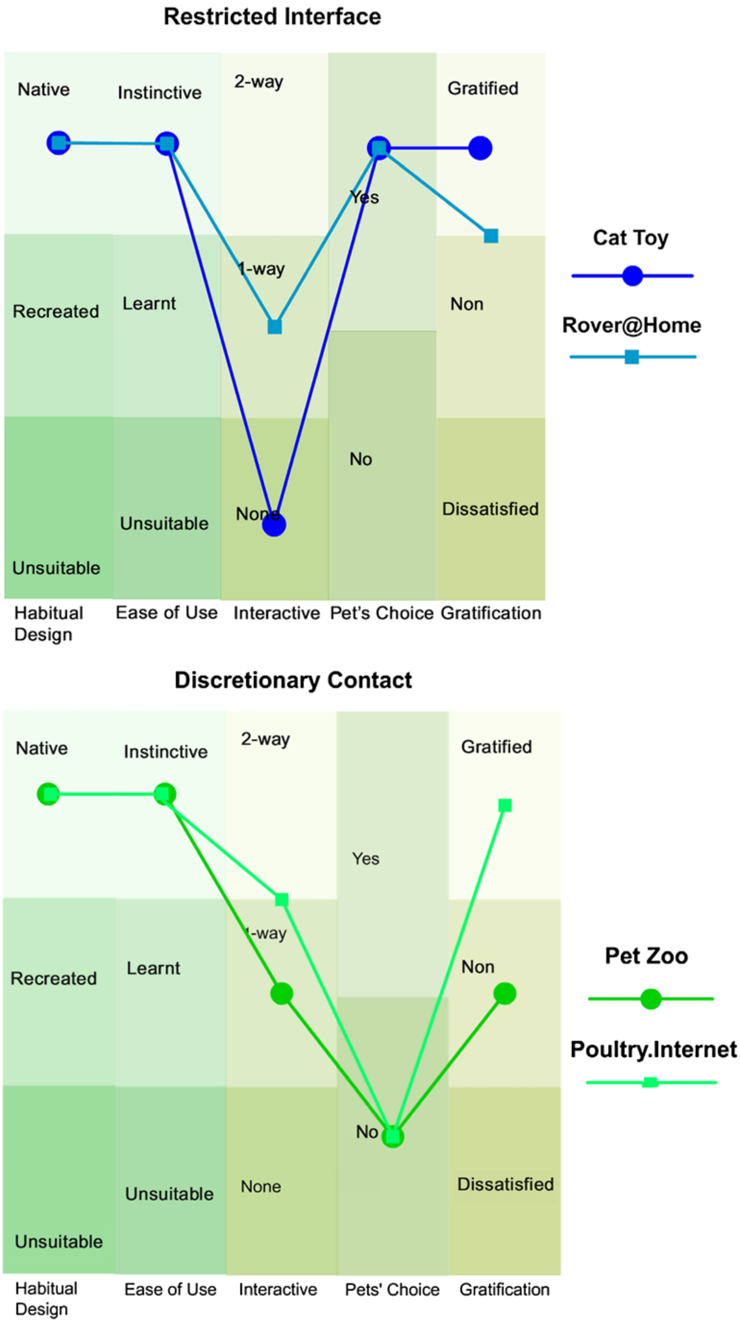

Fig. 4.12 Human–animal interaction systems across five design dimensions

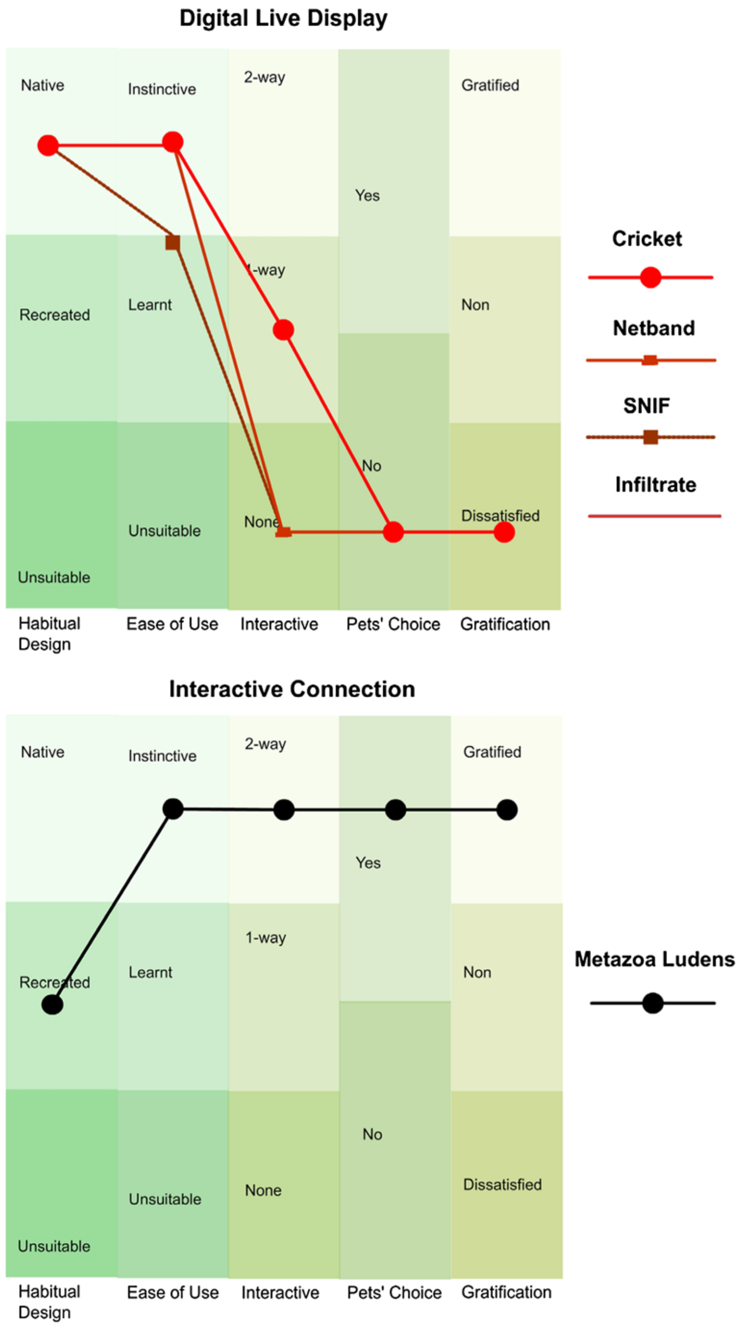

Fig. 4.12 (continued)

Interactive Connection describes Metazoa Ludens. This archetype scores very well in all dimensions except for Habitual Design. This archetype focuses on bidirectional interaction as well as the animal's choice to play and its gratification. It also ensures the ease of use of the system by the animal. Such systems are mostly intended for equal emphasis on interaction between the human and the animal for connection.

While the four presented system designs as models can help designers develop new human–animal interaction systems in the future, they do not represent the only possibilities for building such systems. More important will be the use of the five dimensions in consideration of a new design. In an ideal situation, any such system to be built should be high in all five dimensions and take into account the well being of the animal just as the human's has always been considered. Consideration of their interaction with the system should be intuitive and come naturally to the animals. As such, studies on animal behavior are essential in selecting appropriately the way for the animal to interact with the system. Most importantly, the animal's choice to use the system and its gratification from using the system should be essential and not taken for granted, else it will be just a meaningless system created solely for using animals as entertainment for the human.

4.8 Veracity of Telepresence

Like all remote interaction systems, one main concern with this system is the issue of veracity of telepresence and the related epistemological issues, that is, how one can be sure the other remote party is who he/she claims to be; in this case, how the human can be certain that he/she is playing with a real live hamster and not a digitally controlled one. These issues could be mostly solved by providing live video and audio feeds of the hamster during game play to the human, together with the virtual world. Nevertheless, this problem of veracity of telepresence is a generic one, existing in most remote interaction systems and has been extensively discussed in other works [8, 37] more focused on telepresence, and thus we feel it is out of context for this work.

4.9 Conclusion

Metazoa Ludens presents a mixed reality game which allows game play between humans and small animals (like hamsters) over the Internet. This system not only allows a novel game play but also allows humans and hamsters to interact meaningfully and effectively with a mixed reality system. This type of interaction offered gives the enrichment and enhancement of the experience as brought about by a digitalized system. While not trying to replace conventional interaction between humans and small animals, its aim is to offer remote interaction with the small animals as well as another way of interacting with the small animals through advanced digital technology. We not only showed detailed experimental verification and positive results, but deeply aimed this work to provide lessons and frameworks for future human–animal media designs for the benefit of animal and human relations.

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Chapter 5
Poultry Internet

5.1 Introduction

In days gone by, most people lived on the land, or were hunters/gatherers, or nomads. People would spend many hours with their animal friends and helpers. For example, cowboys and their dogs in the prairies, aborigines hunting with dingoes in Australia, and Asian villagers keeping chickens in their homes. However, in our modern, global, city age, people are too busy to spend time with their pets. This is part of the phenomenon of modern life, where people are getting farther from each other and from nature as well. Society's uncontrolled development results in modern humans feeling isolated and lonely and lacking a sense of value [39]. Nowadays, one of the few things that bring warmth to our hearts and home are pets. They are the symbol of nature with absolutely non-machinery behaviors. We can express our kindness feelings by fondling them. Thus in our modern lives, we need a mechanism to feel a presence with our pets, no matter where we are, at work or on business.

Unfortunately, we are not allowed to bring pets in our offices and releasing them alone in the backyard makes us always worry about them. The basic solution for this problem is to use 2D video monitoring (or surveillance) systems using one (or more) cameras. But these systems bring only little sense of presence with no tangible or tactile interaction.

In this chapter, we present a novel type of physical interaction and symbiosis between human and pet with computer and the Internet as a new form of media. Our system is a human–computer–pet interaction system that transfers the human physical touch through the Internet to the pet and at the same time transfers the pet motion in real time with a physical doll movement on our low cost X–Y positioning table. Figure 5.1 depicts the general schematic view of the system. As can be seen in this figure, our system consists of two physical entities. We define the *Office System* as the space and setup at the owner's office premise; it is here where the owner touches the doll and sees its physical movement that follows the pet motion. This, in fact, can be anywhere and not just in an office. We also define the *Backyard System* as the space and setup where the real pet is situated. The Office System and the Backyard System are remotely separated and are both connected to the Internet.

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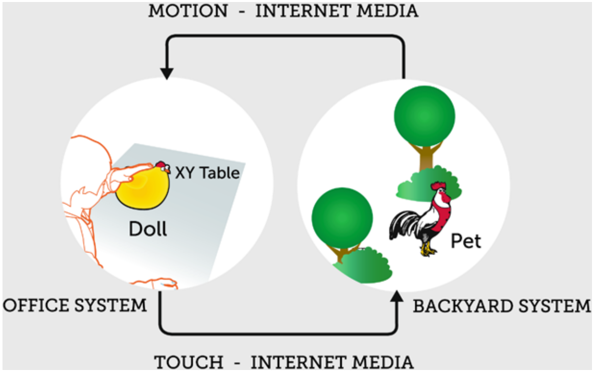

Fig. 5.1 The general schematic of our system

The pet wears a special light weight haptic dress embedded with vibrating actuators and whenever the doll is touched, the action is transmitted through the Internet to the pet dress, the vibrators are activated, and the pet feels the sense of touch.

In our system, we focus on poultry as our pets. This is because poultry are one of the worst treated animals in modern society, being mainly used for meat and egg production in tiny cages and quite terrible conditions. However, it has been scientifically proven that poultry have high levels of both cognition and feelings. Therefore, there has been a recent trend of promoting poultry welfare and also of keeping poultry as pets [8]. Poultry should have the same status as other pets such as cats and dogs because of their similar level of cognition and feelings. It has been shown that chicken are easily capable of observational learning [29]. They also have intelligent goal seeking and declarative mental images (when looking for a goal object they have a definite mental image of the object rather than following a set of rules to reach it) [16].

As they are cognitive and intelligent animals, we should be concerned about their welfare. In animal welfare, it is not necessary to know exactly what an animal is feeling, but the important thing is to know whether the animal feels bad or feels good [12]. A good amount of study has been done on investigating the major states of suffering in poultry (such as fear, frustration, pain, and discomfort) [15]. However, until recently there has been little work on positive subjective feelings in poultry and other animals. However, more and more researchers are becoming interested in a systematic investigation of pleasure in animals and poultry. In the Gordon Memorial Lecture of the World's Poultry Science Association in 2001, it was stated that "There will always be things that have to be done to poultry 'for their own good' that will reduce their welfare. It may be possible to counter-balance unavoidable negative feelings by understanding and promoting positive feelings." It has been shown that poultry are animals that experience pleasure [13]. Thus it is important to develop systems that also promote poultry pleasure. We hope similar research can also be extended to all maltreated domestic animals.

Table 5.1 Modes of interaction between a human and a pet

Mode of interaction	Description
Physical presence	Pet movement on an X–Y positioning table
Haptic sense	Touching real doll as an avatar for the pet
Remote touching	Transmitting human touch information to the pet
Physical stimulation	When the pet moves, the user feels it by physical stimulation on her feet

Thus our motivations for this research are summarized as follows: Poultry are important animals with feelings which are treated poorly by society, and thus it is of value to treat them as our companion pets, as well as promote their pleasure. However, in modern cities and societies, it is difficult to keep poultry as pets, particularly in working and office conditions. Therefore, the motivation of this work is to use mobile and Internet technology to improve the welfare of poultry by creating positive feelings towards them, and to allow humans to feel connected to poultry even if they cannot be physically present with them.

The interaction between a human and a chicken is through a mobile wearable computer system on the chicken and a tangible interactive system for the human. The system uses multiple modes of interaction which are summarized in Table 5.1.

We understand the perceived eccentricity of developing a system for humans to remotely interact with poultry. Most interaction-oriented research focuses on human–human interaction rather than human–poultry interaction that has been focused on in this research. However, we would like to emphasize that this work has much wider significance and applications, as it paves the way for humans and animals to work together in a collaborative way based on equal partnership, as well as provides important points for multimodal human–human interaction.

We think that human–animal interaction is unique in a sense that animals do not respond to human linguistic (or verbal) expressions in a straightforward manner, so there is one less dimension as far as multimodal interaction is concerned. This poses a big challenge in developing a system that allows effective human–animal interaction. Hence, this is an area of research worth exploring, yet it has received limited attention thus far. Furthermore, there are applications where remote human–animal interaction is a crucial kind of work, such as that in a rescue operation where trained pets (dogs) gain access to confined places such as dangerous, narrow caved-in tunnels. Using the ideas from this research, we can "see what the animal sees" with a tiny wireless camera connected to the pet mobile wearable computer when it moves around in places which are impossible (or not safe) for a human to go into, and then we can guide and control the trained pet movements by remotely touching different parts of the virtual animal. The ideas can be used for the people who have allergy to touching animals. Using our system, they can see the reaction of the animal to their remote touch. It can even be used in the same way in zoos to have feeling of touch and stroking live, wild animals which cannot be done in normal conditions due to the danger.

This chapter has been organized as follows: In Sect. 5.2, the psychological pleasurable effects of touch interaction between human and animal on both sides are shortly described. In Sect. 5.3, we review the related works on remote tele-haptic systems and also the previous works on human–pet interaction. We give a brief relation of this system to a cybernetics system in Sect. 5.4. Section 5.5 explains the technical parts of our system. In Sect. 5.6, we describe the experiences with our system. Section 5.7 looks at the possibilities of extending our work to non-pet applications, and in Sect. 5.8 we provide conclusion and future works.

5.2 Motivation for Human–Pet Touch Interaction

In the past few years, there has been an increase in interest in relationships between humans and animals and in particular with the animals that we keep as companions. In this section, we discuss the benefits of pet ownership both to the owner and to the animal.

5.2.1 Why Do We Keep Animals as Companions?

Pets have been cited as providing social support which has some advantages compared to the social support given by humans. Pets can make people feel unconditionally accepted, whereas fellow humans will judge and may criticize. Sanders [37] stated that social support by other humans can cause anxiety and worry.

Pets satisfy human's need to nurture. There is evidence that self esteem is an important aspect of social-emotional development of children. Bergesen [3] found that children self-esteem scores increased significantly over a 9-month period of keeping pets in their school classroom. Many parents admit that pets can be valuable tools which can be used to educate children about life events [27].

Beginning in the 1980s, professionals who used animals in therapeutic settings began to make a distinction between animal assisted activities (AAA) and animal assisted therapy (AAT) [6]. AAA provides opportunities for motivational, educational, recreational, and therapeutic benefits to enhance the quality of life, and is delivered in a variety of therapeutic environments by a specially trained professional in association with animals. AAT is a goal directed intervention in which an animal is used as an integral part of the treatment process. A successful prison-based AAT which involved cats, goats, birds and small farm animals [5] demonstrated that inmates who had pets to care for were less violent, had increased appropriate social interaction, had fewer infractions, and needed less medication than those inmates without pets. Animals can be used in therapy setting to teach new skills or to reduce maladaptive behaviors [6].

5.2.2 The Effect of Touching and Caressing on Poultry and Other Animals

Many homes have pets as companion animals, and people enjoy stroking them. Animals often respond by closing their eyes and showing pleasure. Touch is very important to both animals and human beings. In a study by Jones [24], it was shown that poultry farmers could have more productive hens if they installed video screens showing chickens being stroked. It was found that hens that are deprived of human contact are likely to be more anxious and prone to poor egg-laying. However, it is not feasible for the farmer to handle every chicken in today's huge commercial flocks, and further tests showed that for a chicken to watch another one being stroked had almost the same effect.

In another study [36], it was shown that stroking suppresses stress-induced elevation of ACTH (secretion due to maternal deprivation) in animals. The above shows that the touch and stroking are very essential for humans and animals. There might be a situation in which touching them is not possible, for instance, when we are in the office, traveling or in a hospital; therefore, virtual stroking would be helpful when our real presence is not practical.

Thus the above research results provide motivation for exploring a new form of media, emphasizing touch and stroking between humans and animals, where the emotional attachment and sense of presence can be felt even if the human is separated from her pet, while also providing pleasurable feeling of touch in the poultry. Hence, the system described here, provides a new form in interactive and symbiotic media between animals and humans.

5.3 Review of Related Works

In the real world, touch and physical manipulation play a key role in understanding and affecting our environment. As has been proven in academic works, touch is a key advantage for human being to interact, understand, and feel affected by the real environment [23]. The use of the Internet as a medium for transferring human touch could be the next big wave in interaction technology, as it provides haptic sensation of touch for distant users.

In this section, firstly, we briefly review the previous works on remote touch or tele-haptic systems, and after that the previous works on human–pet interaction are discussed.

5.3.1 Previous Tele-haptic Systems

There have been a number of projects that explored haptic interpersonal communication (or tele-haptic communication). Brave [4] presented the InTouch system for remote collaborative communication by bringing a greater sense of touch and physicality to distributed multi-user interactions. This was developed as an enhancement of tangible user interface (TUI) proposed by Ishii in [21]. In that paper, some previous works on tele-haptic field have been cited, such as Telephonic Arm Wrestling [43] that provides a basic mechanism to simulate the feeling of arm wresting over a telephone line or Dents Dentata [18], an elementary "hand holding" device that communicates one bit of information over the phone line to activate a mechanism that can squeeze a user's hand. Also in [30] a system called Walkii (wide area locomotion and kinesthetic interaction interface) is proposed as a multi-modal haptic interface which frees the operator from being bound to a stationary kinesthetic work station.

In [21], PSybench was developed with the intention to provide a generic shared physical workspace across distance. The goal was to allow distributed users to cooperate in an environment which is heavily based around physical objects. It is actually constructed from two connected motorized chessboards. The positions of the objects on the chessboard have magnetic bases so that they can be moved using electromagnets placed on a 2-axis positioning mechanism under the board. It employs sensors and actuators to synchronize the physical states of the objects, or "Telemanipulation" as Ishii called it. This interface provides some degree of visual, yet physical feedback to the user, but it still lacks two things: the mechanism for synchronizing the orientation of the objects, and the tactile sensation feedback.

A multitouch 3D touch-sensitive tablet [26] is based on the technique of capacitance measurement between a finger tip and a metal plate. This is one of the earliest researches into the application of capacitive sensing in HCI. In order to handle multiple inputs at one time, the design of the hardware is based on the requirements of the fast scanning algorithm and on tradeoffs between software and hardware.

SmartSkin [35] introduces a new sensor architecture for making interactive surfaces that are sensitive to human hand. This sensor recognizes multiple hand positions and shapes and calculates the distance between the hand and the surface by using capacitive sensing and a mesh-shaped antenna. On the basis of this sensor technology, two applications of HCI were built. Firstly, it was an interactive table that can track multiple hand positions, which emulates a mouse-like interface. The user could manipulate 2D graphical objects using their bare hands. Secondly, a gesture-recognition pad was developed, which is a more intelligent interactive system as compared to the previous one.

In contrast with all these interpersonal communication work, our system is a telehaptic system between humans and pets, and probably the first system that communicates with a pet over the Internet.

5.3.2 Previous Human–Pet Interaction Systems

Very little research has, until now, been done in the field of human–computer–pet interaction. Most of the work in this field is in robot pets. For instance, Sony has introduced a reconfigurable robot [17] called AIBO based on OPENR, a standard for robot entertainment systems with 4 legs and a head such that each leg has 3 degrees of freedom and it can be reconfigured to a wheel based mobile robot. The AIBO entertainment robot dog can be programmed using OPENR. AIBO has built-in artificial intelligence and has been used in many applications such as robot-assisted therapy in Japan [25]. To some scientists, robots are the answer to caring for aging societies in Japan and other nations where the young are destined to be overwhelmed by an increasing elderly population. These advocates see robots serving not just as helpers (e.g., carrying out simple chores and reminding patients to take their medication) but also as companions, even if the machines can carry on only a semblance of a real dialog.

Then there is the Tamagotchi, a once very popular virtual pet which is currently making a comeback. It was marketed as "the original virtual reality pet". It can be described briefly as a tiny hand-held LCD video game that comes attached to a key chain or bracelet. The objective of the game is to simulate the proper care and maintenance of a "virtual chicken", which is accomplished through performing the digital analog of certain "parental" responsibilities, including feeding, playing games, scolding, medicating, and cleaning up after it. If good care is provided, it will slowly grow bigger, healthier, and more beautiful every day. But if it is neglected, the little creature may grow up to be mean or ugly.

Druin et al. [11] also proposed a robot animal that tells stories for the children. Sekiguchi [38] presented a teddy bear robot as a robot user interface (RUI) for interpersonal communication.

All the above-related work did not use real animals, and instead they used robot or virtual pets. It is easier to make such systems which interact with virtual pets, rather the real animals. However, as will be shown in the next section, there are definite differences and advantages in using interactive research technology with real living animals, rather than robotic or virtual animals. Furthermore, as mentioned above, this research work can have wider impact where humans and real animals work together in partnership, such as in remote rescue operations.

The growing importance of human-to-pet communication can also be seen in recent related company products. Recently, an entertainment toy company [40] has produced a Bowlingual dog language translator device. It displays some words on its LCD panel when the dog barks. As an another example, cellular giant NTT DoCoMo Inc launched pet-tracking location based services for I-mode subscribers in Japan, connecting pets wirelessly to their owners [22]. This is a one way position information interface (non-interactive). However, our system is the first system to allow real time remote interaction with free moving live pets in a tangible manner.

5.3.3 Why Not Just Interact with Virtual or Robotic Pet?

We have looked at several human–robotic–virtual pet interactions. There are advantages of such systems in providing companionship, communication, and interactions between humans and virtual or robotic pets. However, there are also some disadvantages in such robotic–virtual pet systems, and lacking features in the interaction with humans, which have been found in research studies. Behrens [1] criticizes the fact that Tamagotches never die (in fact, they do, but they are born again and again as long as batteries are fresh), unlike a real pet. Therefore, people, especially children, can become confused about the reality of the relationship. Children will no longer treasure the companionship with their pets because even if the pet dies, it can be brought back to life by changing the battery. The lack of such moral responsibility will cultivate a negative psychology which eventually will do harm to the society. After few times children will lose their interest in such a repetitive game; however, a real pet will show new and different behaviors everyday based on its owners actions. This makes the real pet more engaging in the long term than a virtual, or robotic, pet.

Another related psychological study was done using Furby (a realistic, interactive animatronic plush pet that interacts with the environment through sight, touch, hearing, and physical orientation). Turkle and Audley [19] studied a group of young children who owned Furby. Some children panicked when the toys broke, a sign to their small owners that the Furbies had died untimely deaths. They told of midnight calls from frantic parents whose children were beside themselves because their Furbies had suddenly gone on the blink; and then they would rush over to the house with a new Furby, and every single time, the child showed no interest in the new one. The children felt betrayed, taken in, and fooled. It had revealed its nature as a machine, and they felt embarrassed and angry. They were totally unwilling to invest that kind of emotional relationship in an object again.

While we do not deny the fact that robotic dog such as AIBO could provide the elderly with some of the physiological, cognitive and emotional benefits, and while people talk about the advantage of a robotic pet as having a perfect imaginary friend, there is a kind of psychology of connection, but not necessary of a real companionship that grows between a human and a real pet [32]. As for the children, it is not the issue of whether they will love their robotic dogs more than the real pets, but rather what it means to love a creature and to feel you have a relationship with a creature that really *does not* know that you are there. According to Turkle [32], simulated thinking might be thinking but simulated feeling could never be feeling, simulated love could never be love, and it is important to always keep it mind that no matter how convincing and compelling this creature in front of us, this is still just simulation. Hence it can be seen that if the interaction between a human and an animal is replaced with an equivalent system with a human and a virtual or robotic animal, there are definite disadvantages and differences in the emotional response and feeling of companionship. It is thus proposed that it is critical to develop a remote interactive system between humans and biological living animals to promote the human response of true companionship with the animal. Furthermore, as is detailed in the experimental results below, this work is equally aimed at promoting positive feelings of enjoyment in the animal, which cannot be done if only virtual/robot animals are used.

5.4 Poultry Internet as a Cybernetics System

The term cybernetics was originally proposed by Wiener [42] as "the control and communication in the animal and the machine". This emphasized the concept of feedback control as a construct of value in the study of neural and physiological relations in the biological and physical sciences. Wiener's research included observations of how human and machine interact when engaged in purposeful action. He was researching pilot (human)– jet fighter (machine) interaction during World War II. It was clear to him that feedback was involved in the sensory and motor activities that constitute any purposeful action. Also he studied pilot's behavior under different conditions of stress, such as changes in blood pressure under flight conditions, in order to obtain a better understanding of pilot behavior, and ultimately, to be able to design an efficient radar–antiaircraft system. From then on, communication engineering and neurophysiology joined forces in the study of human–machine interaction.

In our system, we use this philosophy to construct a biological–computer feedback system where the pet is part of the cybernetic loop through touch, motion and sound. The human is also in the same cybernetic loop through touch and visual feedback. The computer is part of the system by feeding back and transmitting human and animal feeling and senses. As a newer definition [34], cybernetics uses epistemology (the limits to how we know what we know) to understand the constraints of any medium (technological, biological, or social) and considers powerful descriptions as the most important result. Cybernetics has evolved from a "constructivist" view of the world [41] where objectivity derives from shared agreement about meaning, and where information (or intelligence for that matter) is an attribute of an interaction rather than a commodity stored in a computer [44] (see [34] for more information about cybernetics perspective).

Thus, using the same philosophical viewpoint, we construct a biological–social cybernetics system where the data is not simply a commodity but it is an attribute of interaction. Concretely, digital bits take on a meaning. The bits are carriers of human touch to living pets, and the bits take on a meaning of human warmth and emotion.

5.5 Technical Details of the Multi-modal Interaction System

In this section, we describe our mobile wearable computer chicken jacket along with two major parts of our system, the *Backyard System* and *Office System*, as shown in Fig. 5.1. These two sub-systems communicate with each other over the Internet.

5.5.1 Overall System

The Backyard System is where the real pet chicken is kept (Fig. 5.2, left). It consists of a computer with a web camera attached to it. The web camera monitors a chicken

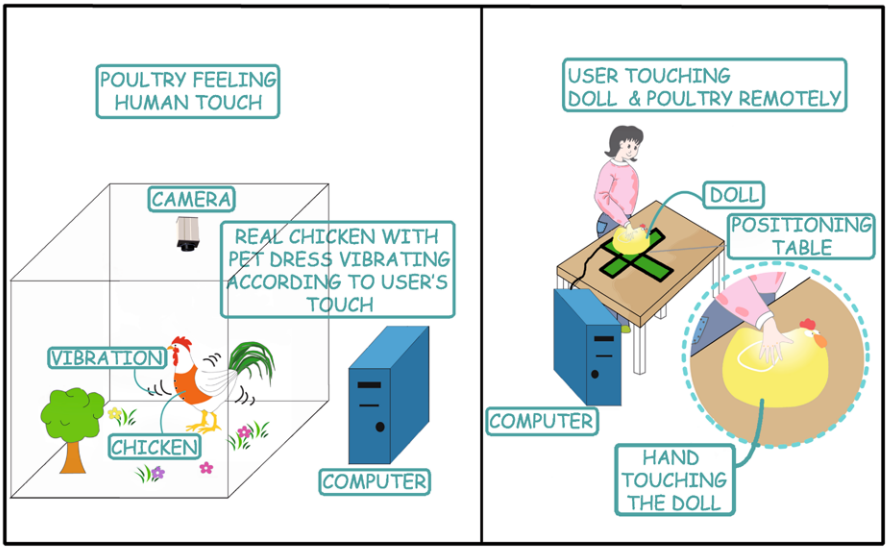

Fig. 5.2 The pet owner touches the doll with embedded touch sensors, and the pet in the backyard feels the touch

house where the chicken lives and moves about. The movement of the chicken is tracked by the camera, and data is then sent to the Backyard computer. Also, the chicken wears a special pet jacket with embedded wireless transceiver and vibrator motors. This jacket receives touch data from the computer wirelessly. Whenever the user touches the pet doll on the Office System, the pet jacket reproduces the touch by activating the vibration motors corresponding to the spot it is being touched.

The Office System is at a remote location from the real pet (Fig. 5.2, right). The Office System consists of a computer with a pet doll sitting on a mechanical positioning system. This mechanical positioning system moves the pet doll in the X, Y and rotational axes. It receives movement tracking data from the Backyard System in real time, and moves the pet doll accordingly. Therefore, users are able to see the doll move in a similar manner to the real pet.

5.5.2 Remote Physical Touch

In order to enable physical remote touch, we use a physical doll as an avatar for the pet. The doll movements are controlled by the computer, and it follows the pet motion in the garden. Here the user has physical interaction with the avatar.

Also the audio-visual information of the pet from the Backyard is received through the Internet. These are displayed to the user on an LCD screen and speakers.

Figure 5.3 shows the Office System. As can be seen in this figure, the user is touching the doll and at the same time she can see the pet in the LCD screen. The doll

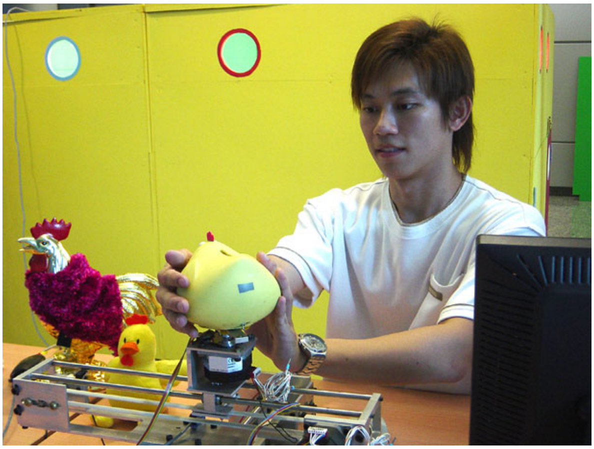

Fig. 5.3 The pet owner touches the chicken pet via the pet doll avatar

follows the real pet motion in 2D by moving on a mechanical positioning system. When she touches the doll, data is transferred to the pet dress and vibrates one of the vibrotactile actuators on the pet jacket according to the part of the doll which is being touched.

The physical touch mode contains two major parts which are described here: the doll which detects the user's touch and transfers it to the PC, and the mechanical positioning system which controls the doll movements based on the pet motion in the backyard.

5.5.2.1 Mechanical Positioning Table

To move the pet on the table, we designed and implemented a mechanical positioning system using two stepper motors for movements in the X and Y directions and also one stepper motor for the rotation of the doll. These position data are calculated based on the real pet motion in the backyard by a computer vision tracking algorithm, and then the tracking results which are X, Y and rotation information are sent through the Internet to the office.

Figure 5.4 depicts the hardware system of the mechanical positioning table. It consists of the X and Y axis structures, each driven by a stepping motor. A third stepping motor is mounted on the carrier of the structure, with the axis of rotation perpendicular to the table. The doll is not directly coupled to the rotation motor (the third one) for aesthetic reasons. We have hidden the mechanism by covering it with a sheet of plastic on the table. By attaching magnets on both the doll and the third motor, the doll follows the motor 2D movement as well as rotation, without direct coupling, as depicted in Fig. 5.4.

Compared to PSybench [21], which gives only 2D position information, our system gives the owner a sense of both pet's position and orientation.

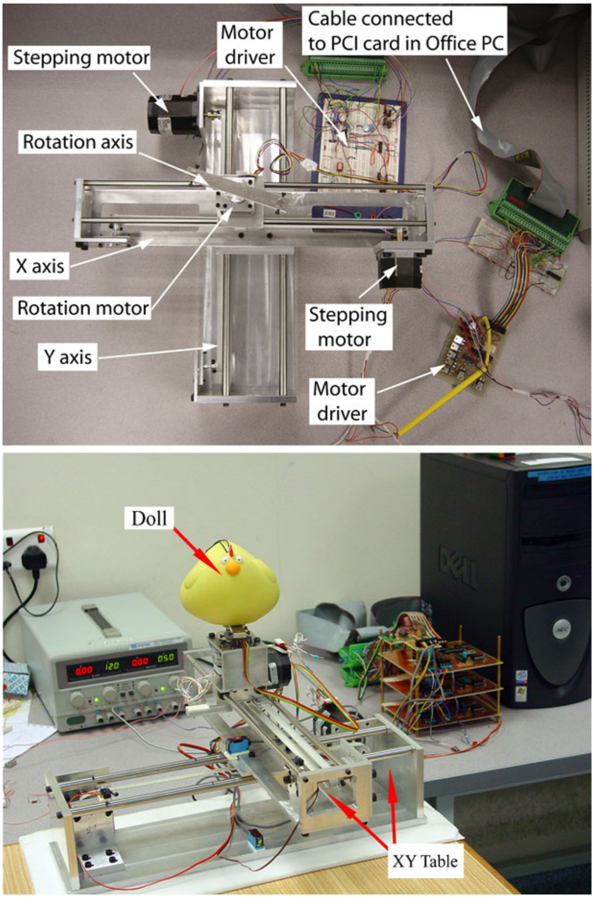

Fig. 5.4 Hardware mechanism of the mechanical positioning table

5.5.2.2 Doll

In the office system, the pet is represented by a real object, a doll. The doll consists of a touch-sensing board, a RF transmitter, a microcontroller, and the doll itself with a hollow body. The aim of this device is to detect the user's touch on different parts of the body of the doll and to send this data (touch event and touch position) to the pet dress for activating the related vibrators on the dress, and thus cause the real pet to feel the touch in the same place as the human touching the doll.

The touch-sensing board mainly consists of the five capacitive touch sensors and a sensor chip QT161 from Quantum Research Group [33]. The microcontroller and an RF transmitter are soldered to the touch-sensing board as well. All five of the capacitive touch sensors are connected to the QT161 sensor chip. The sense field of each sensor pad was tuned by changing the capacitance on the board, so that it would only respond to a massive dielectric object such as the human hand in our context.

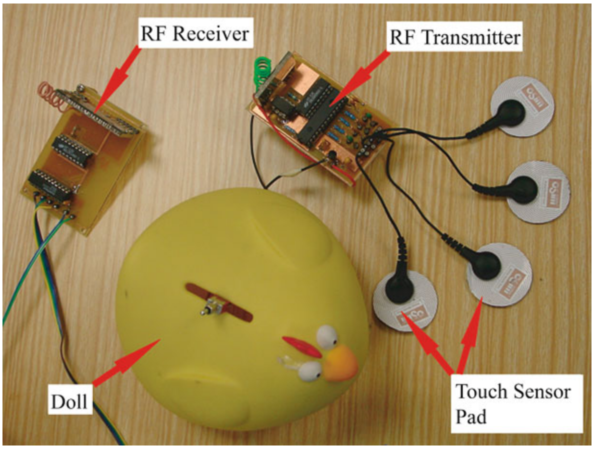

Fig. 5.5 The doll and its electronic devices: touch-sensing board with battery and capacitive sensing-pads

Note that the capacitive touch sensors are operated by placing them inside the doll; thus they are not noticeable to the user. The microcontroller sends a 5-bit (each bit corresponds to a sensor output) information to the RF transmitter. There is also an RF receiver board, which is connected to the Office PC's serial port, that receives the information and sends it to the PC. The PC then transmits the information through the Internet, which then will control the vibrating devices on the pet.

The doll and the touch-sensing board are shown in Fig. 5.5. The inside body of the doll is hollow and we concealed the touch-sensing board and the sensor pads inside. The capacitive touch sensor pads are distributed on various parts of the doll.

5.5.2.3 Mobile Wearable Computer Pet Jacket

We have also provided a special pet dress for transferring the user's touch to the pet. Therefore, the pet can feel whenever its owner touches its avatar at the office.

The main reason of designing a dress for the pet is to make a system that receives touch information from the Office System through the Internet and then transfers it to the pet so that the pet feels the human touch.

There are several ways of conveying the touch sensation, such as vibration, pneumatic and hydraulic. All these tactile display devices stimulate the skin to generate these sensations of contact. In our system, we used high-frequency vibration motors (or vibrotactile actuators; we use the two terms interchangeably) because vibration can relay information about phenomena like surface texture, slip, impact, and puncture. In many situations, vibrations are experienced as diffused and unlocalized.

Here we designed and implemented a jacket with a wearable computer for the pet with vibration motors to simulate a stroking sensation. These vibrotactile sensors give the pet a distributed touch sensation. Also, note that multiple motors could be

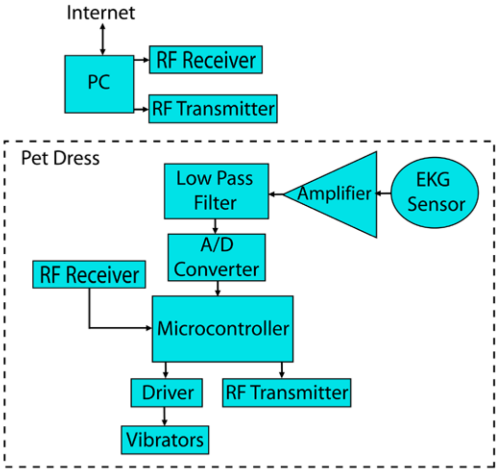

Fig. 5.6 The block diagram of the pet dress

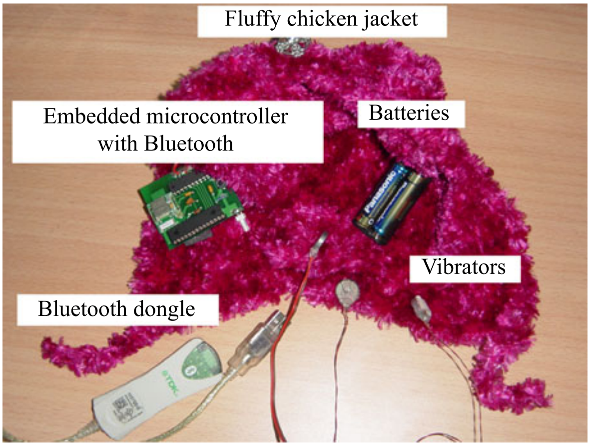

Fig. 5.7 The pet jacket with micro-controller, electrodes and vibrotactile actuators

activated at one time, just like the multipoint sensing of the capacitive touch sensors on the pet doll which is located remotely on the user's side in the office system. The schematic block diagram of the hardware is shown in Fig. 5.6. As can be seen in this figure, the pet jacket contains an RF receiver to receive touch information from the Office System.

The mobile wearable hardware dress consists of an RF receiver to receive data from the Backyard System, a microcontroller to control the vibration motors, and current drivers to supply the necessary current to the vibrators. A consumer 9 V battery is used to provide power for the whole system. Figure 5.7 shows the hardware system and the pet dress. Here we put five vibration motors on the neck, back, left, right and breast of the pet. The total weight of our dress with hardware and battery is just 127 g. Figure 5.8 depicts our pet (a chicken in this application) wearing the

Fig. 5.8 The chicken wearing the mobile computer pet jacket

dress. Many tests on our pet chicken showed that it did not make any problem or discomfort for the pet to wear it (as will be detailed below).

5.5.3 Computer Vision Pet Tracking

We perform the tracking of the pet in two dimensions to understand its location and its orientation in the backyard. It is done by computer vision-based tracking methods. We assume that there is no other moving object in the room except our pet. Hence, we applied a background subtraction algorithm to detect the movement of the pet in the backyard. The input image for detection comes from the tracking camera mounted on the ceiling which captures the whole backyard area. After background subtraction, we calculated hue similarity between background pixels and new captured image pixels to remove shadowed regions. The result is filtered to remove the small regions in the output image. We also modified the background in regions of the image which do not have large RGB disparity to have a robust detection mechanism. As a result the background is also updated in our algorithm for every frame.

The result of the background subtraction algorithm is the position of the centroid of the pet in pixel coordinates. The centroid provides us with the two dimensional coordinate. We also need to obtain the direction the pet is facing, i.e., its orientation. Figure 5.9 shows how we derive the orientation from centroid data. An important assumption made is that the pet is facing where it is moving to.

Using the tracking data obtained in pixel coordinates, we map the position from image frame to the corresponding position on the mechanical positioning table. The image frame size is 640 pixels for the X axis and 480 pixels for the Y axis. The positioning table has a range of 1,000 steps for both the X and Y axes. In order not

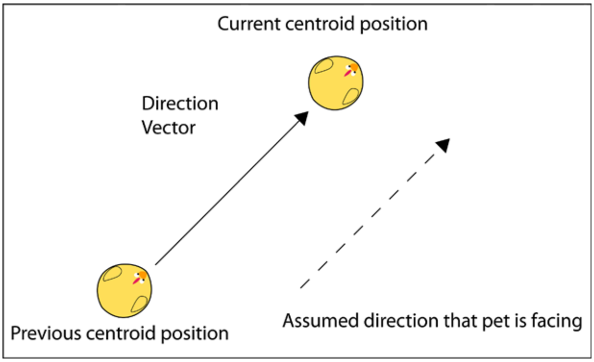

Fig. 5.9 Obtaining orientation from centroid

to distort the overall frame, we keep the ratio of Y to X axis of 0.75 in the image frame. Therefore, to match, we make use of 750 steps on the Y axis and 1,000 steps for the X axis on positioning table. The following equations perform this mapping in software:

$$CurXS = \frac{CurX \times 1{,}000}{640}, \quad (5.1)$$

$$CurYS = \frac{(CurY + 80) \times 1{,}000}{640}. \quad (5.2)$$

CurX and *CurY* represent the image pixel coordinates of the centroid of the pet, while *CurXS* and *CurYS* represent the mechanical positioning table coordinates of the same centroid of the pet. *CurXS* and *CurYS* are in step coordinates while *CurX* and *CurY* are in pixel coordinates for the X and Y axis, respectively.

In determining the amount each motor needs to rotate, we obtain the difference between the current and previous coordinate. After obtaining the results from (5.1), we perform the following:

$$StepX = CurXS - PreXS, \quad (5.3)$$

$$StepY = CurYS - PreYS, \quad (5.4)$$

where *PreXS* and *PreYS* are used to store the previous coordinate values, while *StepX* and *StepY* are the number of steps motor X and motor Y needs to rotate, respectively.

The calculation of orientation makes use of the values of *StepX* and *StepY*, as shown below:

$$\theta_r = \arctan(StepX,\ StepY),$$

$$\theta_s = \frac{\theta_r}{\pi} \times 100.$$

θ_r represents the angular orientation of the pet in radians calculated from the image pixel coordinates, while θ_s represents the same orientation in terms of rotation steps on the mechanical positioning table. θ_r is the angle in radians, and θ_s is the angle in steps.

As the rotational axis has 200 steps for one revolution, π corresponds to 100 steps. This completes the integration of tracking data with the motor control module.

5.6 Experiences and User Studies

People who have participated in and tried out our system experienced the human–animal interactive symbiosis supplied by the system. They saw that the doll moved in real time according to the chicken movement. Furthermore, through the touch interface, the participant stroked the doll and saw in real time that the touch was transmitted to the chicken.

As will be detailed below, the experiments on our pet showed that it was not irritated by wearing the jacket and it acted naturally with the jacket. In response to remote touch with our system, it did not act as a linear constant coefficient system, but we found that it was very sensitive to the vibrotactile actuator mounted on its neck. Most of the time when we tele-touched it from the neck, it moved down its head in the direction of the vibration.

We have done a user study for our system. The interviewees were 31 students (18 male and 13 female) between 20 and 30 years old. They completed our questionnaire after having some experiences with our system. The users were asked to firstly interact with the chicken in the present conventional remote method interaction with pets, a live webcam and monitor. Then the users were asked to interact with the poultry using the physical doll. The users were not given any time limit of interacting with the system. The results of the user study have been summarized in Table 5.2.

The results of Question 1 from Table 5.2 show that most of the interviewed (84%) admitted that our system is better than current telecommunication systems for pets.

As can be seen from the results of Question 2, 84% of the interviewed had a feeling of presence for the remote pet with our system.

The survey shows that almost all interviewees liked being able to touch and stroke their pets when they were out of home and their pets were alone (see the results of Question 4); and as can be seen from Question 3, it was important for them to do that.

Although the results of Question 5 indicate that 48% of interviewees did not like their pets wearing a dress with electronic devices, the results of Question 6 show that most of them (68%) believe the pet had a pleasurable feeling, and they liked the remote touch using our system. Although these results seem contradictory, users stated that due to the novelty of the pet dress it would make them feel “odd” or “unconventional” to put it on their pet, even though most thought it would provide a pleasurable feeling to the poultry. Thus, it seems that there are some contradictory feelings among the users due to the novelty of the system.

Also the user study results show that for most of the interviewed touching was more important to them than the other kind of interaction, i.e., watching their pets

Table 5.2 User study results for our system

1) How do you compare this system with other remote communication methods with a pet such as webcam and phone?	Percentage
Much more better	32.26
Better	51.61
Almost the same	12.90
Worse	3.23
2) How acceptable is the representation of the pet by a doll for you?	**Percentage**
Exactly like the pet being here	3.23
Almost gives the same feeling as a real pet	32.26
Gives a little feeling of the presence of the pet	48.39
I can't feel the presence of the pet at all	16.12
3) How do you rate the importance of having a kind of interaction with your pet when you are in the office or at school, or on holiday, and it is alone back at home?	**Percentage**
More than 75%	22.58
50–75%	51.61
25–50%	22.58
Less than 25%	3.22
4) Do you like to touch your pet when you are in the office and it is alone in the backyard of your house?	**Percentage**
Yes. I really want to do it	25.81
Yes. I want but it is not a necessity	38.71
Yes. It is fine but not so important to me	35.48
No. I do not like it	0
5) Do you mind if your pet wears a dress containing electronic sensors and devices?	**Percentage**
Yes. I like it	9.68
Yes. I don't mind	41.94
No. Prefer not	45.16
No. I won't allow	3.22
6) Do you think your pet will have better feeling when you remotely touch it?	**Percentage**
Yes. It clearly enhances its mood	12.90
Yes. I think it likes it	54.84
No. I think it dislike it	29.03
No. It feels violence	3.23

Table 5.2 (continued)

7) If you are able to interact with your pet, what kind of interaction is more important for you?	Out of 4
Touching	3.29
Watching it in 2D like web cam	2.97
Hearing it	2.06
See the movement of the doll in backyard as displayed on the X–Y table	1.68

through a monitor (Question 7). Our system allowed the users to compare using the proposed system and a normal webcam system, as they could experience viewing the pet using a web cam and monitor only. Then they could directly compare the use of both methods of interaction.

The data analysis showed that females compared to males preferred their pets wearing such a jacket by more than 10%. At this stage, we had not realized the reason for the sex differences, and plan to study this deeper at a later stage.

It was also important to us to test the feeling of the chicken in a scientific manner. It has been shown that in animal welfare it is not necessary to know exactly what an animal is feeling, but the important thing is to know whether the animal feels bad or good [12]. Previously, a significant amount of study has been done on investigating the major states of suffering in poultry [15], but until recently there has been little work on positive subjective feelings in poultry and other animals.

However, there are established scientific tests to prove chicken motivation (to pleasure) and avoidance of bad feelings. Avoidance of bad feelings can be tested when the animal is allowed to choose between certain aspects of its environment and by assuming it will choose in its best interests and welfare. This is the preference testing method pioneered by Hughes and Black who worked with poultry [20]. Hughes has used this method to test poultry preferences for cage floor types, inside or outside environment, cage size, and social conditions.

In order to test poultry motivation for pleasure, we must take an extra step. This is to measure the strength of preference of the poultry. In poultry, there are various methods to do this, for example, by obstruction methods [9]. However, we use the method of Duncan [14] which is to have a weighted push door. This has the purpose of being related to nature, similar to the push of a chicken through undergrowth to reach a goal.

As shown in Fig. 5.10, we created two 3×3 m cages and one small 3×1 m cage interlinked with a push door one colored red and one blue. Each cage contained the same food and water. This test can be described by the sequence of pictures in Fig. 5.11. In the beginning of every experiment, the chicken is placed in a common corridor (I) with a blue door and a red door leading to two separate rooms, respectively. In both rooms, there is food and water (II). If the chicken enters through the red door, it will be left untouched. If the chicken enters through the blue door, the human user will remotely touch it through the pet doll interface (IV). The chicken wearing the haptic pet jacket will feel its owner's touch (III).

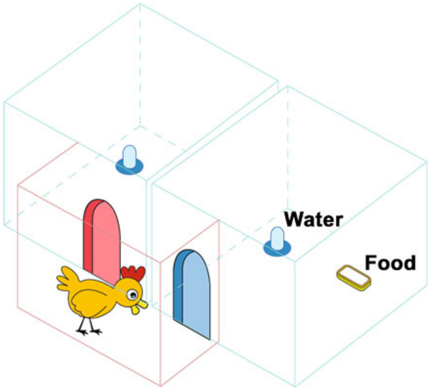

Fig. 5.10 Schematic diagram of our test system for experimenting chicken preference (using the method of Duncan)

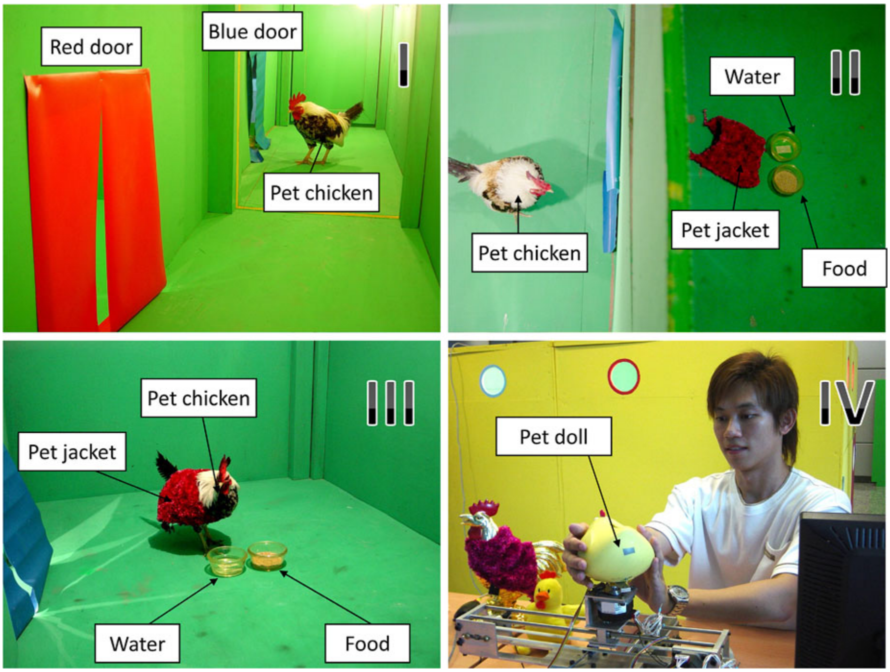

Fig. 5.11 Test for poultry motivation (Sequence I to IV is described in the text)

Over a period of 28 days (testing on two chickens separately) we placed the chicken in the small cage. If it entered through the red door it would be picked up and we put the dress on it and used the system for 10 minutes. If it entered through the blue door, there was no picking up or putting on and testing the dress. This was repeated 200 times (100 times per chicken) over 28 days and it was found that 73% of the time the chicken would choose the red door and 25% of the time the chicken would choose the blue door, and 2% of the time not enter any door after 10 minutes.

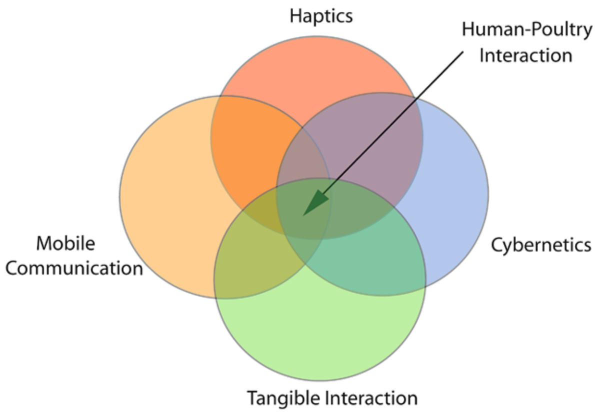

Fig. 5.12 Our system is the intersection of mobile communication, haptics, tangible interaction, and cybernetics

Thus we can conclude that at least there is no negative or bad feeling of the chicken by using the vibrating dress for many periods.

In order to test for positive feeling and pleasure in the poultry, we conducted the same test with a heavier red door (500 g extra weight). The same test as above found that 70% of the time the chicken would choose the red door and 27% of the time the chicken would choose the blue door, and 3% of the time not enter any door after 10 minutes. Although it is a small decrease from the above results without the weight, we can safely say that the poultry positively chose the red door, even though it contained the weight, and found the system pleasurable (which confirms the results previously given in [24] that the poultry positively reacts to touch).

5.7 Wider Applications

This research project is built on the platform of remote multimodal interaction using mobile wearable computer. In general, the proposed system is an integration of mobile communication, haptics, tangible interaction, and cybernetics as shown in Fig. 5.12. Though the application is to human–pet interaction, we need to emphasize that the multimodality is generic, and it can be extended to human–human without loss of genuineness and novelties. We hereby discuss several human-centered applications that fit into the theme of this project.

5.7.1 Multiplexing Existing Communication Channels

Human communicate and interact among each other in rich and complex ways. When co-located we adeptly trade off between a wide range of cues, both verbal and nonverbal [31]. However, when we examine the technological mediated communication tools we use when not co-located, we quickly see our information channels restricted to primarily verbal channels such as text and speech. There is a need to explore nonverbal interfaces between non-co-located people. In places where remote communication already takes place, touch devices could allow people to increase their communication by multiplexing information and emotional communication channels [7]. To enable such ubiquitous and pervasive interfaces, we propose multiplexing of touch and voice information (multimodal) based on the system that we build. The wearable computer dress, when worn on the body, could function as a haptic communication tool. Loved ones, when separated, often want to communicate without interrupting the flow of each other's work by active conversation. For example, when one partner is in a meeting, the other one might want to express support by touching him – that's multiplexing touch and voice. Remote dance synchronization can be seen as another example to this. In this application, both dancers listen to the same music, while the foot strikes of the first dancer are transmitted to the second one to synchronize dance steps.

5.7.2 Intimacy Through Ubiquitous Computing

The extension of multiplexing voice and touch leads us to explore the relationship between intimacy and ubiquitous computing. Ubiquitous computing has long been associated with intimacy [2]. The term "intimate computing" refers to technologies that enhance or make possible forms of intimacy between remote people that would normally only be possible if they were proximate; it is a technology that can express of our intentions, actions and feelings toward others. Very little work has been done in this area. In [10], a working interactive environment is designed using the familiar and intimate space of a bed. This bed environment applies the philosophies of ambient environments for the presentation of background information in order to help humanize inter-personal communication. Similarly, our system could be developed further to suit the subtle philosophies of intimate computing in the following way: both non-co-located persons wear the wearable computer dress with Peltier junction heating device and tiny vibration motors. Also on each dress there is a ECG sensor to detect individual's pulse. Peltier junction is a low power thermocouple device that when electrical current is applied to it, one side of the thermocouple becomes hotter than the other. The feeling of presence of the person can thus be represented through both the body warmth and heartbeat, as realized by Peltier junction and vibration motors, respectively. This provides access to a personal "life signal" of another person. We have just added "body warmth" and "heartbeat" to the multimodalities of human–human remote interaction. For instance, people can feel remote hugging using our system.

5.7.3 Spying/Rescuing Pet

Last but not least, we would like to extend the application of our work to dogs. Police use dogs in sniffing traces of criminal fugitives in bushes; anti-narcotic officers use them to sniff out drugs; rescue personnel rely on them in rescue operation to access narrow caved-in rubble. However, with the advances in technology, the kind of help that dogs render does not really change much over time. Our proposed system can improve the interaction between the human and the animal work as an equal partnership, especially when they are not co-located and the rescuer's command has to reach the dog and be executed faithfully, and, at the same time, the dog's feedback to rescuer has to be timely. Especially in the military and rescue operations, where the dogs carry out surveillance/spying duty in the battlefield or deep in the enemy territory. Using a dog, rather than a robot, to penetrate enemy territory is a major advantage because no robot to this day and in the near future has the agility and intelligence of a dog.

For such an application, we can use our wearable computer dress with an extra camera attached to the dog's head. The light-weight dress, when worn on the dog, will have the dog's body and neck area covered evenly. While the dog is out in the battlefield and if it is remotely tickled, say, on the left side of its body, the dog changes its walking direction to the left as it is trained to respond this way. The wireless camera attached to the head of the dog captures the surrounding view and the video images are compressed by the wearable computer dress. It is then sent through wireless link (Internet) back to the human commander. The commander thus is able to see what the dog sees in real time. As he remotely tickles the neck of the dog, the dog turns its head and sees different views from the camera.

5.8 Conclusion and Future Works

In this chapter, we introduced a novel multi-modal interaction system with mobile devices for human–poultry tangible remote tactile communication. We can summarize our novel points of our system as follows:

- Remote tele-haptic tangible body fondling sensation
- Human–poultry and poultry–human interaction
- Pet–computer control mechanism
- Physical representation of pet in office
- Mobile light weight wearable computer pet dress

The system benefits both the human and the poultry in an equal partnership. As shown in the user study, people like to be able to touch their pets when they are out of home and their pets are alone, and they had a feeling of presence for the remote pet with our system. As for the pet, the experimental results confirmed that the proposed system is pleasurable for the pet, too. The system is specifically designed for sentient beings.

Our experimental results show that for a human having a tactile sensation with her remote pet is more important than watching it through a webcam.

This system can also be used for people who love animals but cannot touch, hug and stroke any pets because of their sensitive skin or allergy. With this system, they will not worry anymore about this and can have enjoyable time with their pets. Even with this system, people can feel a new kind of touching not only with pets but also with wild animals. For example, it would be nice for children and adults to go to a zoo and be able to enjoy stroking the lion mane.

Our cybernetics interaction system is able to connect not only people and animals but also people and people together in a new symbiotic manner. This is an example of new technologies for families. With this technology you can remotely touch and stroke the one that you love.

Although the mechanical positioning table for displaying the 2D movement of the pet is bulky and takes some space of the table in an office environment, the reader should note that it is an prototype system, and it can be improved and made smaller in order to be used as a commercial product.

We now propose possible improvements that can be made to our present work.

We can use a robot doll with more degrees of freedom instead of mounting a simple fluffy doll on a mechanical positioning table in the office. Then the robot doll in the office will follow the movements of our pet in the backyard, which will give us more realistic representation of our pet. Also it would be more handy to carry around.

Also in future work, we will better measure the strength of human touch on the doll, instead of just sensing it as a high ('1') or low ('0'). In this way, the frequency and amplitude of the vibration is adjusted according to the strength of touch, giving us a high fidelity tele-haptic sensation. In psychophysical experiments, correlated variations in the frequency and amplitude of the stimulators extended the user's perceptual response compared to varying amplitude or frequency alone [28].

We can use our system in a rescuing application with a trained dog pet moving in an unsafe area for human. When the pet feels a touch on the left or the right, it will move left or right. We will "see what the pet sees" with a tiny wireless camera connected to the pet wearable computer. Or a small trained pet can help to check small areas such as when checking pipes in a power planet.

In conclusion, we must say that interacting with a living being is more pleasurable and important for humans than interacting with a toy. Nowadays, one of the few things that brings warmth to our hearts and homes are pets. They are the symbol of nature with absolutely non-mechanistic behaviors. We can express our kindness feelings by stroking them. Thus, in our modern lives, we need a mechanism to feel a presence with our pets, no matter where we are, either at work or on business. The proposed system is one of the solutions to bring this togetherness to us, no matter how far we are from our poultry companions.

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Chapter 6
Age Invaders: Entertainment for Elderly and Young

6.1 Introduction

Due to the aging global population [20], intergenerational entertainment is becoming increasingly important. Based on our initial user studies with Singaporean older people between 60 and 80 years old and young students between 10 to 12 years old, none of the older people participated in computer and electronic gaming activities while all the young students were engaged in games for a substantial amount of time weekly. Although the older cohort does not object to their grandchildren playing games, and they are inclined to play together with them, they have failed to do so due to the steep learning curve to play the games. The older cohort has elaborated that the steep learning curve is attributed to mouse and keyboard interface, graphic user interface and language used in the games. Our finding is also consistent with some literature review [4, 21, 24], which stated that one of the main reasons that elderly users have been under-represented in computing is that until recently hardware and software designs, particularly interfaces, have simply not been designed to accommodate them.

It would be beneficial if the older people could interact actively with the young family members through gaming activities. This could possibly strengthen family bonding and bridge the gap between older people and youth culture. Studies show that greater participation of the older people and young in computer-related activity benefited both parties [12]. In addition, one of the key factors why people play is due to "the people factor," since players use games as mechanisms for social experiences [16]. Players in groups emote more frequently and with more intensity than those who play on their own. However, according to the recent Goo Research survey results on over one thousand married women in Japan between the ages of 50 to 69 [9], only 6.5% of the users play computer or electronic games with their grandchildren. Furthermore, very little work is found on developing intergenerational computer games, and very few systems facilitate multiplayer physical interaction.

This chapter illustrates the design process of four main prototype iterations of a mixed reality intergenerational family entertainment game. We aim to develop an interactive system that can be played by the grandparents, parents and grandchildren

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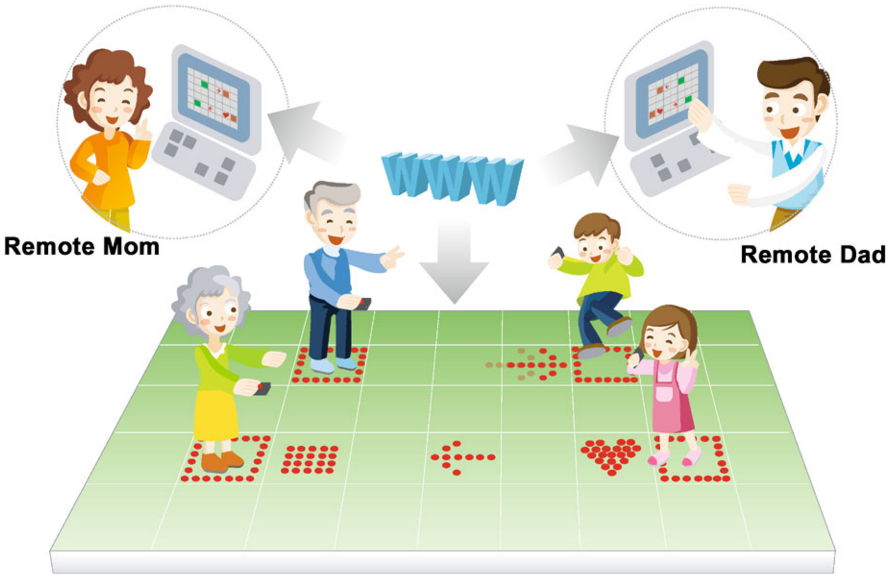

Fig. 6.1 Age Invaders – an inter-generational, social and physical game

simultaneously, as shown in Fig. 6.1. Previously, we have developed Human Pacman [5], a novel interactive mixed reality entertainment system that ventures to embed the natural physical world seamlessly with a fantasy virtual playground by capitalizing on mobile computing, wireless LAN, ubiquitous computing, and motion-tracking technologies. It emphasizes collaboration and competition between players in a wide outdoor physical area which allows natural wide-area physical movements. We were inspired to develop a family version of Human Pacman which encourages a high level of social and physical interaction. In designing an interactive system for older people and children, ease of use was one of our main concerns, as we wanted to rely on the physical interactions of the players' movements without the burden of heavy game equipment, for example, the wearable computer and head mounted display which can impede movement and reduce the level of enjoyment of the game.

We show the progression through the initial stages of the research to the Age Invaders game prototype which has been shown worldwide as noted in [14, 15]. We share the overall design process steps and the design decisions that carried the system through each iteration. We give special attention to illustrating the involvement of children and older people in the design process as they are critical users of the system. Their technology proficiencies are widely different, and therefore part of the challenge was in developing a system which was simple enough to be understood by the non-gamers, yet engaging for the skilled gamers as well. We then present discussions about the design options for the next iterations of the system, which will be yet another large step in creating a more flexible, physically interactive, mixed reality system which brings innovation to group interaction for players of all ages. We will also present the design of a toolkit that eases the programming of the Age

Invaders system, to accommodate for the artists and designers who may not be familiar with programming languages like C and C++. We hope that the toolkit would encourage creation of new type of artwork and entertainment applications.

6.2 Related Work

Findings from scientific research studies show that playing video games can lead to changes in an individual's pleasure, arousal, dominance, and/or affiliative behavior [6, 18, 25]. Furthermore, it has been shown that older people enjoy computer gaming experiences [26]. Participation in an activity helps older people feel better and healthier as they recognize their ability to move and create something [17]. According to a recent report, moderate, regular exercise may be just as helpful in combating serious depression in older people as antidepressant medication [1]. Therefore, it is worthwhile to investigate how we could use digital technology to improve the well-being of older people through social interaction, physical activity, and entertainment.

Commercial arcades have recently seen a growing trend in games that require human physical movement as part of the interaction. For example, dancing games such as Dance Dance Revolution (DDR) and ParaParaParadise by Konami are based on players dancing in time with a musical dance tune and moving graphical objects. Some game systems have offered Exergames [2], which use the electronic game format to promote exercise, but these are often lacking in the ability to motivate the players. These systems still force the person to stand, more or less at the same spot, and focus on a computer screen in front of him.

Recently, the Brain Age games on Nintendo DS have gained huge popularity among older Japanese [8]. The older players believe that such games can sharpen their thinking, and they enjoy playing the games very much. On the other hand, Nintendo Wii has gained tremendous popularity and has sold over 6 million consoles since its launch in late 2006 [27]. To play the games on the console, for example, in Wii Sports, the player physically swings and moves the Wii remote, which goes beyond the micro movements of just pressing buttons. In addition, iGameFloor [10], a recent research project that uses an interactive floor platform for social games and entertainment has shown that children are generally motivated by the use of bodily interaction. Thus, we believe that there is a growing need and trend for video games which promote physical activity and mental stimulation for children, adult, and older people as well.

The physical nature of mixed reality games has been explored more in recent years, showing positive benefits of high user motivation to play and to quickly establish bonds between the players [19]. In the Human Pacman mixed reality game [5], players enjoyed high levels of enjoyment in the context of social and physical interaction.

6.3 Design Methodology

Our approach is "Design-oriented Research," whereas our efforts are primarily research focused and aim to find appropriate use of media to understand and address a perceived human problem [19]. The creation of prototypes is secondary to the search for knowledge and understanding of difficult issues. With this in mind, we must also consider that our field of research is not focused on the human alone, but also the role of the machine in mediating communication and providing new situations and contexts of use. The driving force is in improving human issues in the world and understanding how technology can be crafted to be a tool and facilitator of communication. Our problem statement focuses on two groups of users with very different levels of acceptance of technology and tolerance for usability problems. In the design of the system, we had to make a system which was easy enough for the elderly to participate and to hold their confidence in the technology and motivation, yet also challenging and fast paced for the younger players who are technology experts and who are easily bored when faced with simple interactions. We set out to design the system which is not a simple productivity application, but a system that is an open platform encouraging interaction and promoting fun social gaming. We followed a User Centered Design approach in defining the steps for our research prototype development. These steps borrow from existing models [11], yet do not call for an in-depth risk analysis as in business application development. This allowed the researchers to design the interactive system quicker and provide workable prototype iterations. Our process also involved the use of highly proficient game players as advocates for the elderly players before the elderly experienced the game for the first time. We involved these expert players to advocate and facilitate for the older people during and after the game play as well.

The design steps we followed include problem identification, problem exploration, setting the design goals, design requirements of prototype, research user needs, research context of use, design idea generation, prototype creation, and usability studies. These steps will now be described with attention given to the considerations needed when designing for intergenerational family entertainment. Each iteration returned to the beginning and followed a subset of the design cycle in attempts to understand the user better or to overcome a technical challenge. In later sections, we also describe the prototype iterations and discuss the results from the user studies.

6.3.1 Problem Identification

Singapore has a rapidly aging population, as in many countries around the world, and the trend shows that the family is a strong source of financial and emotional support to older people. According to census data, the majority of those aged 65 years and above live with their children and grandchildren [22].

There is a growing trend of commercial games that require human physical movement as part of the interaction. However, there is still no entertainment platform that is designed specially for older people and children to play harmoniously together.

The problem was identified as follows: "How can a digital gaming system be created that will encourage intergenerational physical and social interaction, considering the unique needs of the users and the varied proficiency with technology?"

6.3.2 Problem Exploration

We carried out a preliminary user study to understand the users better, in particular, the grandparents and children in the context of Singapore. The results of the study are presented below.

Singapore has many senior citizen focused community centers, each located among the clusters of high rise residential apartment buildings. These community centers offer a common place for older people who are living in the vicinity to socialize and participate in activities. The facilities commonly offered include televisions, tables and chairs, exercise equipment, etc. The older people normally gather at these centers during the daytime. We have carried out initial observation-based studies at one of the community centers, "Peace Connect," which serves as a general model. We did the studies twice over a period of one month. We observed that there were many older people sitting around the tables. Some were watching TV and playing board games, but most of them were idle. There was little social interaction among the older people there, and they exhibited little motivation to exercise or move around, even though there were treadmills and other exercise equipment provided. They looked tired and most of the time they rested in their seats. This was explained to us by the support staff as being normal.

We conducted verbal surveys with ten older people in a focus group session during our second visit and realized that all the older people were illiterate or had very limited command of written English or Mandarin Chinese. They communicated verbally in the Chinese dialects of Hokkien or Cantonese.

In a similar process, we carried out a focus group study with 10 school children of ages 10–12, from a neighborhood primary school. 80% of them indicated that they play electronic games, ranging from personal computer games to console games such as Microsoft X-box and Sony PlayStation for more than 10 hours a week. On the contrary, 100% of the 10 older people aged 60–80 in our focus group study reported that they have never played any form of electronic games although they were aware of them.

From the initial study we observed the following trends:

1. Many of the older people in Singapore live under the same roof with their children and grandchildren. There is strong bonding between the three generations.

2. Besides the student who does not have grandparents in the family (only one out of the 10 students), the students reported spending, on average, 10–20 hours with their grandparents doing common activities such as board games, card games and swimming.
3. 80% of the children indicated that they play electronic games ranging from computer games to console games for more than 10 hours each week.
4. Older people do not play electronic games and do not have computer related experience.
5. Older people are supportive of the grandchildren playing the games, although they have no understanding of the content of the games, nor do they understand how to participate.
6. All of the 10 older people did not attempt to understand the games played by their grandchildren, primarily because they are apprehensive about using computer interfaces like the LCD screen, keyboard and mouse, and do not understand the language used in the game.
7. The older people are interested in playing games similar to DDR which promote their body movements as a form of exercise. The students that had played DDR enjoyed playing it.
8. Older people are hesitant to try DDR because of the fast paced nature of the dancing game, which is perceived as too demanding for their physical ability. 100% of the older people expressed that an entertainment platform that could allow them to play with children must have an adjustable game speed so that the game pace can be calibrated to suit both parties.
9. Parents are busy at work and often not around at home. They only return home late at night.

From the above observations, in the middle class Singaporean context, older people and children spend substantial time together as a family. A majority of the students play and enjoy computer gaming experiences. Their familiarity with electronic games and their skill level is much superior to the older generations. There is no widely used computing platform which allows children and older people to play together.

6.3.3 Design Goals

Based on the observations above, we established the design goals for Age Invaders as listed below:

1. *Intergenerational family entertainment* – We wanted to create an entertainment system that would enable different generations, the grandparents, parents and children to participate in meaningful game play that could possibly strengthen family bonding.
2. *Physical and tangible interaction* – Based on the above study, we have identified that the barrier for older users to participate in computer games is attributed to

computer interfaces like keyboard and mouse, which seem difficult to use, and a lack of understanding of the language used in games. We propose using body movements as the interface to the game, replacing the need for a keyboard or joystick to participate in the game. Besides being intuitive, it should also double as a form of exercise and the game controllers should be easy to use and have tangible interfaces with big buttons that are easy to manipulate.

3. *Social interaction* – Although there is an emergence of multiplayer games, the interface to the games still remains largely in the form of individual two dimensional screens to facilitate user interaction. In some cases, this is a portable screen, such as with personal game consoles. In either case, it forces the user to use the media to facilitate the interaction which can cause a loss of richness in sharing meaning and emotions. Furthermore, from our initial study, all the older users felt uncomfortable interacting with the computer screen interface. Hence, we envisioned a system that would allow players to interact with each other in close physical proximity, while augmenting the experience with the logic of the digital game.
4. *Remote interaction* – Parents in a modern society often have mobile and digital life styles. They may be busy at work and go frequently on business trips; hence, it is not always possible to physically interact with their family. To further enhance family interaction and bridge the physical distance between family members, we included a virtual world interface so that parents can join in the game in real time, remotely through the Internet with the players at home.
5. *Adjustable game parameters* – The older people in the study expressed apprehension to participate in entertainment games because of their incompetence with the technology and the pace of such activities which are perceived as too fast for them, such as the DDR game. Hence, by having adjustable game parameters that could be tailored for users of different levels of physical fitness and competency with the game, we could potentially balance the game play between the older and young players.

6.4 Design Requirements

In this step, we identified the design requirements for the prototype. This phase takes into consideration the factors including user needs, context of use, available resources, and time constraints.

6.4.1 Resources and Time Constraints

The research lab takes into account the number of resources and skills available to develop the project. Because the funding of the lab is based on various sources, the tentative dates for the subsequent prototypes were established, but the features to be included remained undefined until the findings from each prototype were released.

6.4.2 User Needs

As older people are hesitant to engage in computer related activities, the system should support our interaction design goals by not intimidating older people with traditional interfaces such as keyboard, mouse, and monitor. To support physical interaction, the player's body should become the interface to the system. Instead of fiddling with a keyboard, the players should move their bodies to manipulate the digital elements in the game or entertainment system. Dedicated controllers that are intuitive and simple to use should be introduced. To support both physical and social interaction between players, movement over a big space is recommended. In respect to that, tracking of the players in that space is required. However, we do not want to overwhelm the players with heavy equipment. Thus tracking should be invisible to the players, and the accessories of the system should be wireless in order to limit the hindrance on physical movement in the game space.

From the preliminary user study, we have identified adjustable game parameters as being an important factor in sustaining the players' interest. The older players emphasized that the game should not be too fast such that it would be tiring, nor too slow so that it would become boring.

6.4.3 Context of Use

The system is envisioned as being installed in the home setting. Given this constraint, the system dimensions should be reconfigurable according to the room size. We envisioned the floor platform to be constructed from blocks of square tiles to facilitate this. For example, in houses with more space available, we could construct a larger floor platform consisting of more tiles and fewer tiles for rooms with less space available.

Standard walking width as specified by a common standards handbook is best at 38 cm [13], so the 42 cm square is more than adequate to allow for this. It should be noted that these guidelines use a full sized adult man as a reference, and we understand that this size specification does not apply to all people. Another point to note is that the physical player in our game uses only one of her feet to register the position on the board, so if the player is not able to or feels more comfortable occupying more space, it is quite simple and comfortable to do so.

For parents to play the game remotely from their workspace, the game server is connected to the Internet so that virtual clients can join the game in real time.

6.5 Design Idea Generation

In this step, we carried out brainstorming sessions. We explored popular card games, board games and puzzle games that are popular in Singapore such as Mah Jong, memory card games, and Rush Hour. We also looked into music and dance games such as Dance Dance Revolution (DDR).

We also explored popular arcade games such as Pacman and Space Invaders. We were inspired by Human Pacman, in which the players were transformed into characters of the game. We decided to bring Space Invaders out of its original arcade form, transforming grandparents and grandchildren into human space invaders characters, and enabling them to play the game harmoniously at home. Parents at work can also join in the game's virtual world remotely through an Internet browser, thus allowing all three generations to play together.

6.6 Prototype Iterations

In this section, we provide an overview of the prototype iterations from the first prototype which addressed more technical issues, through the more recently tested prototype, which allows for more complex game experiences.

Prototype 1 was a simple proof-of-concept system, which consisted of 5 floor blocks with light emitting diode (LED) display and built in radio frequency identification (RFID) readers for tracking of player's movements. The prototype confirmed that the players were comfortable moving on the platform, and that their position could be registered by the system. The players also tried launching lasers using the customized space gun. This prototype aimed to verify that the system was usable and enjoyable to all the players. Two main issues were identified in this prototype. Firstly, implementing the RFID readers on each block of the floor display would be very expensive when the system platform is expanded to a bigger room-sized grid. Secondly, the space guns used were not suitable for family interaction due to the implicit violence and were too large in size and too bulky to carry around during game sessions.

In Prototype 2, we redesigned the RFID reader to be in a pouch strapped on the player's leg and the antenna placed inside the shoe. The RFID tags were placed on the floor grid. RFID tags were significantly cheaper than the reader, hence we could cut huge costs using this new design. We also redesigned the space guns to be a simple handheld controller approximately the size of a mobile phone with a simple button to activate the laser beams. We have developed the online virtual player interface and most game functions were implemented. The virtual players can play with real players simultaneously over the Internet. In this prototype, we have implemented two games, the Age Invaders and the Rush Hour puzzle game. Age Invaders was much more favored over the puzzle game due to the physical nature of the game and fast tempo of the interaction.

In Prototype 3, we redesigned the floor platform to be rearrangeable and flexible in the number of squares. We have also redesigned the smart slippers to have an embedded RFID antenna, so that the player has only to wear the slippers in order to start playing. This prototype was fully functional with the inclusion of sound in the game. We have carried out most of the in depth user studies on this version of the system.

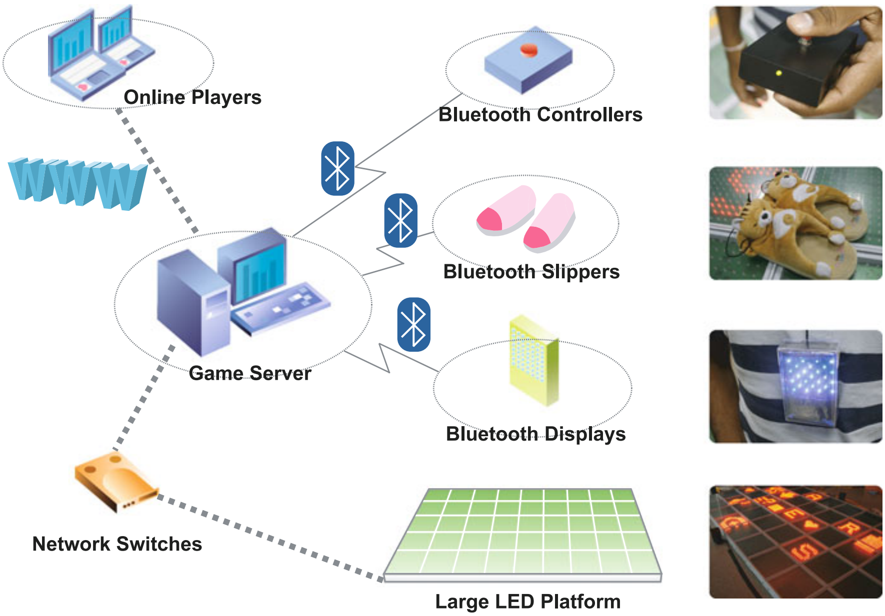

Fig. 6.2 Age Invaders system architecture

In the present prototype, based on the user studies results, we are improving on the smart slipper design, the handheld controller to include vibration and multicolor LED feedback, spatial sound effects, and the development of a toolkit to allow rapid prototyping and reprogrammability of the system in a relatively short time by artists and designers of various skill levels.

6.7 Current System Description

6.7.1 System Architecture

The system architecture is shown in Fig. 6.2, which consists of a home entertainment system and multiple 3D virtual online clients. The heart of the home entertainment system is a game server which is responsible for handling inputs and outputs of the system in real time. The game logic resides in the server. The game server is connected to the Internet to synchronize the game play between the home system and the virtual clients. Inputs of the system include wireless game controllers for triggering events in the game, wireless smart slippers with embedded RFID readers for tracking the position of the players, and control parameters from the virtual online clients. Outputs of the system include a large LED floor platform for displaying the objects and events of the game, wireless lanyard style LED displays, and a 3D virtual player interface for displaying the virtual world of the game.

Each players is equipped with a Bluetooth controller. This controller only consists of one button. When this button is pressed, a laser is released in a straight direction towards the opposing team, similar to the traditional Space Invaders game. The controller's interface was kept simple because it is meant to be user-friendly to the older generation. When the button is pressed, information regarding the device and the action is sent to the game server via Bluetooth. The players also wear wireless LED display for displaying individual player's event, for example, when the player picked up a bonus item, the display will show a flashing pattern.

The wireless smart slipper has an embedded RFID reader that reads the RFID tags beneath the platform. Each RFID tag was programmed to contain a unique string of information that identifies its coordinate. In this way, it is possible to determine which block the player is standing on. Information of the block identity and the player's identity is transmitted to the game server via Bluetooth communication. As the players move on the floor platform, their coordinates are tracked and translated to the virtual world in real time, creating a seamless link between physical and virtual worlds.

The current floor LED platform comprises 45 individual sub-panels. Each sub-panel communicates with the game server using the user datagram (UDP) network protocol. During the design phase of the Age Invaders platform, it was a requirement that the size and shape of the platform is customizable. The solution was to assign each sub-panel a unique IP address. All the sub-panels are connected to a network switch which is concealed in the platform, and there is only one cable connecting to the game server. This setup is very neat and does not require messy wiring. Each sub-panel comprises two micro-controllers, PIC18F452. The first micro-controller is in charge of the network communication between the sub-panel and the game server. It is responsible for extracting the data packets sent from the game server and relaying the data over to the second micro-controller, which is in charge of controlling the display of 256 LEDs on the sub-panel. The micro-controller firmware is capable of lighting up any combination of LEDs to form the desired light patterns. The micro-controller manipulates the LED display via four cascaded MAX7219 chips, each controlling 64 LEDs.

In order to lower the amount of information transfer between the game server and the floor platform, we have included an electrically erasable programmable read-only memory (EEPROM) in each sub-panel. Instead of the game server sending data of the images to be displayed, the images are pre-stored in the local EEPROM, and upon receiving a command from the game server, the sub-panel micro-controller fetches the image data from the local EEPROM, manipulates the position and orientation of the image and finally displays on the LEDs. This allows for a faster refresh rate of the display of each board, and is critical for rendering frames of animation.

We have introduced various features in the firmware of the micro-controller to efficiently automate flashing and moving animations, and to support distributed computing. Timer interrupt in the micro-controller keeps track of when to update the display. In this manner, the server does not constantly send command information to each sub-panel to refresh the animation image, thus reducing the amount of communication between the game server and the floor platform. The server only needs to send the specification for an animation once, for example, the image number, start time, stop time, start coordinate, end coordinate, etc. to the sub-panel, and the animation process is handled by the micro-controller. There is less computation needed on the game server as it is distributed to the micro-controllers in the sub-panels. The firmware uses Bresenham line algorithm [3] to draw the moving path of an animation. This algorithm was chosen because it is very efficient and only makes use of integer arithmetic, which is very friendly to assembly language programming. We also make use of inter-frame dependencies for prediction of the next frame of an animation based on the current frame. The next frame of animation is rendered into the micro-controller's data memory, thus saving the time required to retrieve the image from the EEPROM later. When it is time to refresh the display, the pre-rendered frame in the data memory will be output through the four MAX7219 chips. This achieves the concept of double buffering, which improves the refresh rate of the display.

6.7.2 Game Play

The concept of the Age Invaders game is shown in Fig. 6.1. Two children are playing with two grandparents in the interactive physical space, while up to two parents can join 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. In the situation that not all family members are at home, it is possible to play the game with only two players (one in each team). Our study results suggest that users prefer four-player games because the games were more exciting by having a team member to engage in cooperative competition.

Grandparents and grandchildren wear lanyard-style Bluetooth LED displays for the purpose of displaying game events, including loss of energy of their virtual avatar. The players wear special slippers with RFID tracking and a Bluetooth enabled handheld controller device.

Each game session lasts for up to 2 minutes. The players gain points by picking up bonus items and avoiding laser beams. Each player starts off with 5 energy levels. The player is out of the game when his or her energy level drops to zero. The game ends prematurely if the energy levels of both players of the same team become 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 opponent is hit by the laser beam, she will lose one energy level. The opponent can avoid the approaching laser beam by hopping over it or simply moving to the adjacent squares. 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.

Fig. 6.3 The Invaders have to follow the footprints on the floor during the game

In order to make the difficulty of the game balanced between the young and older people, Age Invaders imposes additional 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 are presented with two squares that are adjacent to their current position to which they can move, as shown in Fig. 6.3. There is a timer which requires the advancement of steps in each period of time, after which an energy level is deducted. This period is determined by the invader 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 energy level by following the footprints correctly ten times in a row.

The parents as virtual players, can drag-and-drop barriers or energy power ups in the shape of hearts on the virtual player interface, and appear almost immediately on the physical game board rendered in patterns of lights. The physical players can pick up the energy power ups to gain extra energy. The barriers will block laser beams. Parents can also adjust the game parameters as mentioned previously, including the 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 being restricted to their indicated squares

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

6.8 User Studies Results

Initial study results were presented in [15] using Prototype 2, where the players' enjoyment in the game was evaluated against the criteria highlighted in Penelope et al. Game Flow [23]. We have also carried out enjoyment and playability study with younger players who have familiarity with contemporary electronic gaming, as presented in [14] using Prototype 3. The aim was to improve the system from the usability and enjoyment standpoint, before engaging the older players. This chapter presents subsequent studies using Prototype 3 that looked into intergenerational playability and enjoyment issues.

6.8.1 Intergenerational Player Study

In order to validate the enjoyment and playability issues when played according to the design goals, we conducted intergenerational studies as shown in Fig. 6.4, with the same users described in the Problem Exploration section. The details of one such study helped to inform on the aspects of the game which were enjoyable and identified issues impeding the positive experience.

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 players reported that they play some type of game, while only 30% of the older players reported playing games with their families. Those who do play games with their families reported similar types of games regardless of age. They reported playing chess, cards, board games, and scroll.

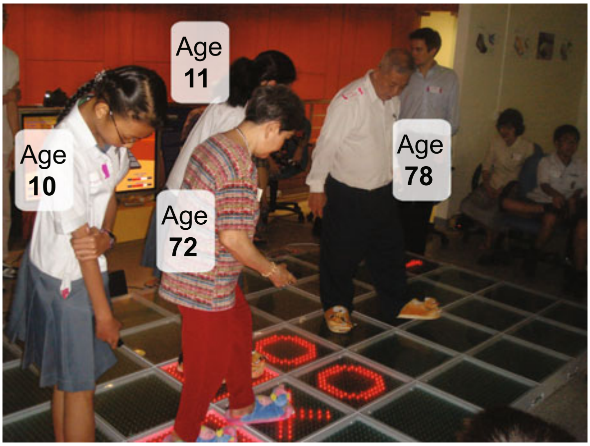

Fig. 6.4 Old and young players taking part in a gameplay session

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, the players overwhelmingly enjoyed the game experience, with all respondents reporting a positive sentiment, and with nearly all respondents showing positive experiences and only one reporting a neutral experience.

6.8.2 Focus Group Session with Older Players

Five weeks after we conducted the initial user study for the older and younger people, we went back to the senior center to conduct a follow-up focus group session with 7 of the older players. Our aim was to investigate the longer lasting impact of the Age Invaders game. When prompted to describe the most memorable aspects about the game, all of them mentioned the launching of lasers, avoiding lasers and chasing after the hearts on the game board. We identified that for the older players, the memorable actions in the game are physical in nature. The player has to press the physical button on the wireless controller to launch the virtual laser and in the cases of avoiding lasers and chasing after the hearts, the players have to physically move their bodies.

"This is a fresh idea and it was my first time playing" one of the older people said, and all agreed. They were all excited about this new entertainment platform.

The older people have never performed any computer related activities or played electronic games before and were afraid to attempt them. However, the players saw this physical game system as being so different from traditional computer systems that they were not only comfortable using the system, but they were also having fun interacting with other players while playing.

When asked what skills were involved in playing the game and how difficult it was to play, all agreed that the game was easy to learn, and that the game speed was fine. A few mentioned that the pace could be a little slower in order to play for a longer period 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. An interesting description was stated by one of the players: "The game gives me good exercise. When you see a 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 doubling the game as a form of exercise. We also noticed that the older people enjoy moderate physical activity that challenges their visual–motor coordination.

When asked about how much fun the game had when played, 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 older players have enjoyed the game and have high motivation to play the game again. Of particular interest is the fact that the users do not see a strong connection between this system and traditional electronic gaming and computing, in general. This high motivation level is valuable by itself as a confirmation that older adults can be engaged in new technologies and have high enjoyment levels. Ongoing research is underway to understand the long term use of the system.

6.8.3 Physical Interface Design Issues

In designing an interactive system for older people and children, we aim to have high levels of physical and social interaction among players on interfaces that are easy to use and at the same time require minimal wearable equipment. The large physical floor display replaces the need for head mounted displays for playing mixed reality games. Virtual objects are displayed on the large display on the floor. The older users reported that they were able to recognize the virtual objects displayed on the floor display immediately and appreciated the bright, easy-to-understand symbols.

To be registered in the game, the players have to wear the smart slippers with a built-in RFID reader. 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 provided by the older players was to use an adjustable Velcro strap to adjust the tightness of fit.

On the other hand, all of the older people were able to understand that the game board was registering their physical steps. Using footsteps as a control mechanism in the game is intuitive for them. Most of the older people in our study recognized

Fig. 6.5 Floor square lit up when a player steps on it

the floor platform as similar to the popular Dance Dance Revolution (DDR) dance platform, which they often see young children playing on in arcade centers. It is possible that they have already developed a mental model of such a stepping interface, hence it may have increased their acceptance of our floor-sensing interface. Also, many of the older players noted that when they stepped on a square, the light for that square lit up, as shown in Fig. 6.5. This gives immediate feedback to the users that their action is being registered by the system, and it reinforces the claim that they understood the purpose of this feature.

80% of the young players gave feedback that the handheld controller should have haptic feedback for the game events, for example, the reduction of an energy level. They explained that due to many tasks they need to perform during the game, feedback that does not require their active awareness, for example, vibration feedback, is much preferred. The group of older people did not have this concern. They may not have had exposure to this type of multi-modal experience in a game setting previously.

Each player wore a lanyard style wearable LED display which hung around their neck that lit up during game events, for example, when hit by a laser, when collecting bonus items, etc. None of the users in the study looked at their own display. We found out that it is not intuitive nor easy physically, to have the users look at the display while playing the game. One suggestion is to integrate the display into the handheld controller. For future improvement, we will incorporate vibration feedback and an array of multicolor LEDs on the handheld controller as a form of feedback of game status and events.

6.8.4 Physicality Issues of the Virtual and Physical Player Roles

The Age Invaders platform involves the players in a physical game space arena focused on a room-sized game board with 45 tiles, each representing a physical position the players can occupy. Physical players register their position in one square at a time since the size of the square is just large enough for one person to stand. While occupying a square, it is reserved for their avatar in the virtual world enforced by the game logic.

The presence of the virtual player is felt on the physical game space by the evidence of their activities in the virtual game space including the placement of barriers and hearts or by changing the speed of the laser beams. The virtual player's activities were not easily understood by the physical players as being activity directed by the human player versus coming from the logic of the computer program.

The physical activity of the players in the game space involves moving the body amongst the 45 squares of the game board and using a small handheld controller to launch laser beams in the game space. The physical interaction with the handheld controller is the same amongst the players, but there are significant differences in the physical experiences of the players' positional movements, which vary depending on the team of which the player is a member. For the child players, the movements must follow the indicators on the game board. The child is presented with two squares that are adjacent to their current position to which he or she can move. There is a timer that requires the advancement of steps each 3 seconds, after which a health level is deducted. This adds the sense of urgency to the physical movements and can be adjusted to an appropriate timer speed by the virtual player. We have identified a footprint timer range of one to three seconds to be the most exciting for the young players. Most young players felt the game was challenging because they have to take care of a few tasks at the same time, for instance, following the step patterns, avoiding the approaching laser beams, and trying to launch one. We observed that the footprint makes the game physically more interesting and challenging to the young and less demanding for the older people, and they have the freedom to move to any position as they do not need to follow any sequence of steps. This matches the physical effort to the desired amount of movement that the adult prefers. Through the nature of the team competition, the adult is compelled to move into a position to take offensive action, but can easily reduce the amount of movement and play from a more defensive style.

Most players who had experienced the game play from the virtual player role expressed that they found the game play experience less enjoyable than the physical player role. This could have been for a number of reasons which might include the following:

- The physical players interact in a more social situation in which they see the other players
- Interaction in the physical space involves natural conversation and body language
- Interaction in the physical space adds the element of performing onstage for others, while the virtual player does not receive the same feedback

- The physical exertion of the virtual player is much less and involves small hand movements with the mouse and keyboard

A possible avenue for future development could be to represent the virtual player's avatar in the physical space and participate as a player at the same level. This could allow for a virtual player that has to dodge laser beams and follow dance steps just like the physical player, as opposed to acting as a referee or just balancing the game play. This could be realized with a robot in the physical game space, which the virtual player could control. In place of a robot, a virtual character could be used, which could be represented as a special avatar on the physical and virtual game space.

On the other hand, the interface for the virtual player could be modified to include a more physical interaction as well. For example, a DDR-style dance mat could be used to give the physical exertion component to the virtual player who is participating via the Internet and is located far from the physical game space.

6.9 Software Libraries and Toolkit

The software libraries and toolkit were developed to allow artists and designers, who may not be proficient in C++, to program the Age Invaders system easily. The software libraries and toolkit allow them to program interactive games and experiences without the knowledge of the firmware and hardware details of the system.

A C++ library was developed using Visual Studio, which provides an application programming interface (API) for the floor display platform. This library communicates to the platform via Ethernet using the UDP protocol. Two libraries were built. The "Tier 1 library" is a collection of functions that serve as an interface between the programmer and the platform. It allows the programmer to access the instruction set of the firmware without knowledge of the exact bytes that need to be sent. The "Tier 2 library" allows the programmer to regard the entire platform as a single entity. This library lets the programmer feel as though she is programming something similar to a computer monitor instead of a platform that consists of many individual blocks. The library handles shifting of images across blocks automatically. In the Tier 2 library, an image class, AIImage, is defined. This class handles all the manipulation of images on the board. It has parameters such as picture number, x and y coordinates, layer, type, and priority. Several functions allow the programmer to alter these parameters and manipulate the images.

The library layer is coded in the C++ language, and thus requires a programmer who is adapt at C++ to program new applications. In addition, it does not update the boards automatically. Every time a change is made, the programmer has to update it accordingly. A toolkit was thus created in MAX/MSP visual software programming environment to help simplify the programming task. MAX/MSP supports both high level and low level programming. It allows programmers and engineers to program in the C and C++ languages, and designers and artists, who may not be proficient in programming language, to program in a simple visual programming environment.

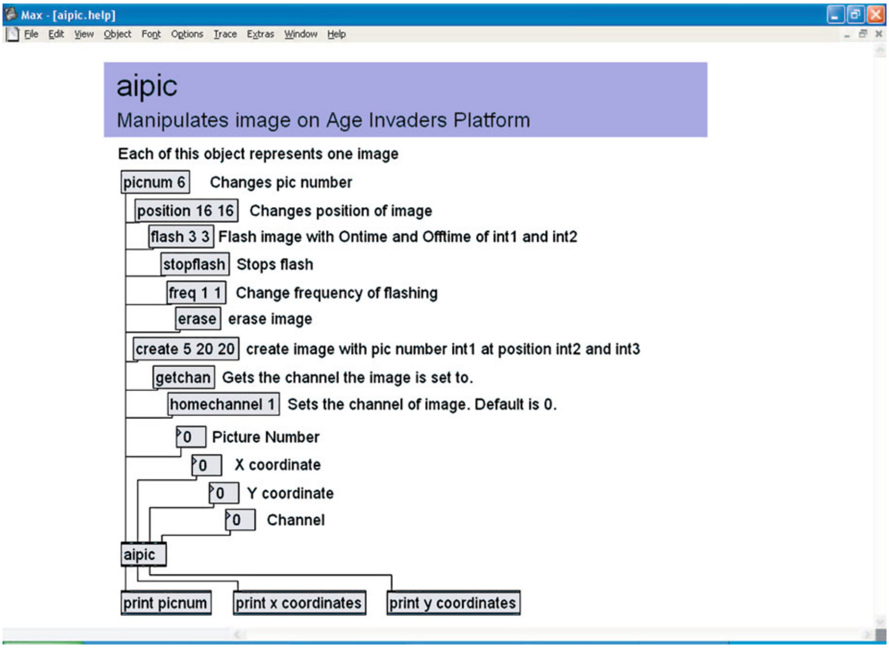

Fig. 6.6 Aipic MAX/MSP external object

External objects were created in the MAX/MSP environment, which allows the programmer to communicate with the floor platform easily as well as to retrieve input from various Bluetooth devices, for example, the body display, shoes and the controller. To use these objects, the user simply clicks on the object box and types in its name. The designer can also use any existing objects in MAX/MSP to connect to the library's objects.

Some of the external objects that were created are presented below:

Aipic Object This object has 4 inlets. The first inlet accepts integers as well as messages. The other three inlets accept integers. There are two outlets in this object, the first one outputs the picture number, and the second one outputs the coordinates of the image. Each Aipic object represents an image on the Age Invaders platform. On each panel, there are 4 layers and thus 4 of such objects can be displayed on a single panel at the same time. Several images can be grouped by putting them in the same channel and moving them all at once.

Shoe Object This object allows the shoes to read the shoes' position on the board using RFID reader and send the shoe and position information back to server via Bluetooth.

Convert Object This object convert the board position to coordinate for displaying images as a shoe position is tracked.

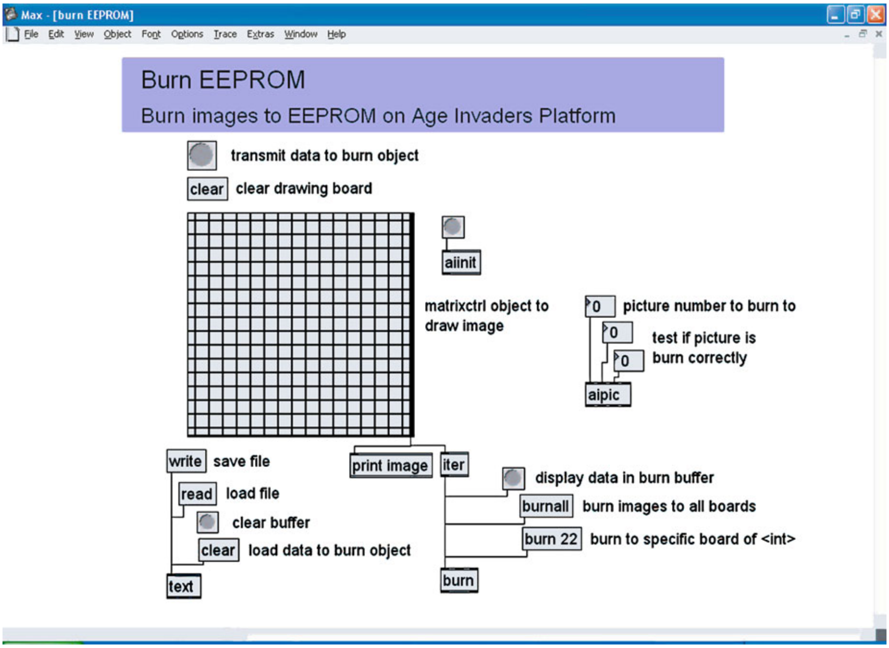

Fig. 6.7 Burn MAX/MSP external object

Instrument Object This object allows the user to load a VST instrument[1] and play music notes. The first inlet accepts a bang. The second to fourth inlets take in integer inputs and the last inlet takes in messages.

Burn Object This object allows the designer and programmer to simply draw a new image and burn it to the EEPROM in real time. Previously, in order to store an image on the EEPROM, each EEPROM (45 in total since there is one in each board) had to be physically removed and placed into the EEPROM burner. Now the image can be burnt into the EEPROM via the Ethernet connection and the images can be displayed immediately. The ease of adding and displaying images makes the toolkit ideal for artistic creation. It provides instant feedback and the ability to adjust the layout directly on the board.

Screenshots of the Aipic and Burn objects are shown in Figs. 6.6 and 6.7.

[1]Steinberg's Virtual Studio Technology (VST) is an interface for integrating software audio synthesizer. VST uses Digital Signal Processing to simulate traditional recording studio hardware with software.

Fig. 6.8 Magic carpet concept design

6.10 Product Development

The Age Invaders system, together with the software libraries and toolkit, can be developed into a future product such as a new magic carpet system. The concept is shown in Fig. 6.8.

Magic carpet could have the following main features:

1. A vibrant color pattern display to complement a person's mood and his or her living room's interior design
2. An RFID sensing feature that would turn the carpet into a mixed reality gaming interface
3. Novel interactive intergeneration social-physical games that allow the elderly grandparents to play harmoniously together with children on the carpet, while parents can participate in the game play in real time remotely in the virtual world through the Internet
4. A connection to the game server via WIFI, hence eliminating messy wiring
5. Modular design allowing customizable dimension to fit into any living room
6. Rollable design also providing easy storage and ease of bringing out for outdoor activities, e.g., picnic

A magic carpet could offer an intuitive way for the elderly to get into the world of entertainment and gaming, without the need of understanding complex game controller interfaces. It does not involve bulky equipment and massive setup. The players could enjoy immersive mixed reality games at the comfort of their homes. When not in use, it is a beautiful carpet that enhances the interior design of a living room.

Its modular design allows customizable dimension to fit into any living room. It can also be rolled up for outdoor activities, for example, picnic and family outings, where it would be powered by its internal rechargeable battery.

6.11 Conclusion

This chapter described the design issues and decisions made during the development of Age Invaders, with the goal of promoting social and physical interaction across the generations. We utilized the user-centered design approach of keeping the needs of the user central to the project development, constantly validating our assumptions by testing incremental changes and having later stage tests involving game sessions closer to the intended context of use. By following this method, we have been able to create a system which has not only met the user needs for physical interactive entertainment, but has served to better understand user interaction in the mixed reality context. The extensive user studies helped to shape and construct the physical dimensions of the system starting from the earlier stages and including setting the size of the game squares and the handheld control device. Later refinements guided by the users included changes to the virtual character role and also highlighted the key strengths of the game scenario. It was precisely the physical nature of the game system that presented the older players with a digital game experience they could easily understand. The older players, who normally express concern and apprehension about computers, were able to enjoy the interactive system and were anxious to try new games made for the platform. The social aspects of the game play were appreciated by two distinctly different groups of players who would not normally play together. Through the variable game parameters, the effort level for all players was set according to physical abilities, which ensured that all players were challenged physically, yet still fostered collaborative competitive play. According to our findings, when making design decisions in developing intergenerational family entertainment systems, the use of one portion of the user base, which is most proficient with technology before involving the novice users, should be considered. This was found in our research to empower the novice users to accept digital technology and increased the playability of the game. With the addition of toolkit that supports quick prototyping and ease of programmability of the system, we hope that more artwork and entertainment applications would be created.

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Chapter 7
Huggy Pajama: A Remote Interactive Touch and Hugging System

7.1 Introduction

As we move further into the digital age, we are growing physically further apart from family and friends. In today's modern urban lifestyle, working parents are constantly kept apart from their children at home by work commitments and business trips. Children are often in the care of others, or left at home as 'latchkey kids', while parents are constantly balancing between work and the family life, often worrying about the well being of their children. The rapid development of society brings about a vicious cycle that can result in feelings of isolation, loneliness and a lack of sense of value [42]. While the proliferation of computers and the Internet enables us to exchange information and perform certain tasks in a quicker and more efficient manner, we are isolating ourselves from the real world where actual physical touch is very important as a communication means. Touch is able to signal deeper meanings than words alone. It enables us to communicate on a social platform at deeper affectual level compared to mere words, better signaling affiliation and support. For example, while the exchange of words may vary in the greeting and farewell rituals of family members, friends and even political representatives, these rituals consistently involve tactile exchanges such as hugging, kissing or shaking hands [26]. Likewise, interpersonal touch as seen in team sport accompanies or replaces verbal communication during exciting moments in the game. Touch is also important in smaller groups such as dyads, when one individual shares positive or negative news or seeks support and confirmation [25].

This problem is more pronounced for parents with young children. Children of these young ages need constant care, guidance and love [13]. Parents are generally able to reach their children by telephone or video phone, but communication purely by voice or video lacks the physical interaction which has been shown in previous research to be vital in effective communication [1]. Younger children might have difficulties understanding the true meaning of words spoken by their parents. As a consequence, we require a more effective way of remote communication between parents and young children. While it may not always be possible for parents to decline work commitments (such as long office hours and business trips), remote

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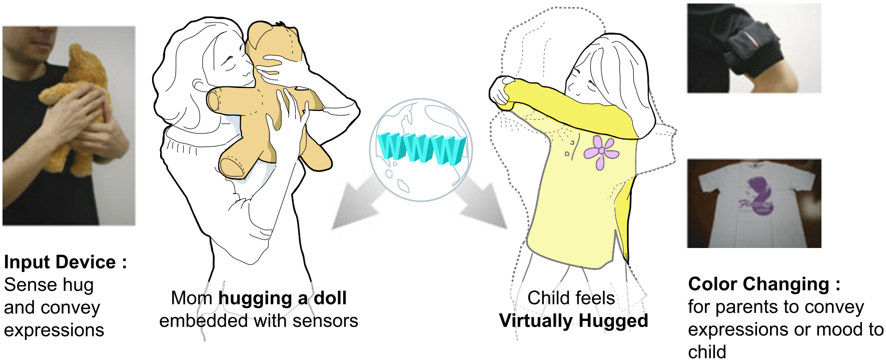

Fig. 7.1 Overview of Huggy Pajama

haptic interaction may be a feasible alternative when the parent must be away from the home.

In this chapter, we present a novel type of physical interaction system for parents and children to communicate using haptic means through the Internet. Huggy Pajama is a mobile and wearable human–computer–human interaction system that allows users to send and receive touch and hug interactions.

Huggy Pajama consists of two physical entities. On the one end, a novel hugging interface takes the form of a small, mobile doll with embedded touch and pressure sensing circuits. It is connected via the Internet to a haptic wearable pajama with embedded air pockets, heating elements and color changing fabric.

A general overview of the system is shown in Fig. 7.1. On the left of the figure, an input device acts as a cute interface that allows parents to hug their child and send mood related cheerful expressions to them. On the right side of the figure, connected through the Internet, an air actuating module and color-changing clothing reproduces the hug sensation and connects the parent and child.

This pajama is able to simulate hugs to the wearer in the form of pressure that is accurately reproduced according to the inputs from the hugging interface accompanied by the generation of warmth, color changes of the fabric according to distance of separation between parent and child, as well as displaying emoticons.

Our system provides a semantically meaningful interface that can be easily understood by children and parents as a reproduction of hugging. Furthermore, the hug sensation is produced in a calm and relaxing way through gentle air actuators rather than through vibration or other mechanical means. We aim to have an "impedance matching" between the input (a soft, cute, calm touch sensing interface) and output (ambient, calm, cute, hugging output).

Although never intended to replace real physical hugging, we believe this system would be of great benefit for times when the parent and child cannot be at the same physical place. Related research provides scientific evidence which showed that infant monkeys grew up to be more healthy when artificial contact comfort was given even in the total absence of their real mothers (although it would be unethical to carry out the same tests to deprive human infants artificially) [23].

Table 7.1 Modes of interaction for Huggy Pajama

Interactive modes	Description
Remote touch and hug	Transmit human touch and hug on doll to wearer of haptic pajama
Haptic pajama	Reproduce hug sensation and warmth on wearer
Distance and emotion indication	Color changing clothes and accessories to give indication of separation distance between parent and child, and emotion data

The interaction between parent and child can be bi-directional. The parent and child each can wear the pajama. Each interacts with the other through a mobile hugging interface. The bi-directionality is left as an option for the users, because at this stage, such a wearable device is not suitable to be worn at work for parents. The interactive modes are summarized in Table 7.1.

Huggy Pajama focuses on developing a mobile hug communication system for parent and child, and provides a realistic soft touch sensation. We enable users to hug or touch different areas on the hug sensing interface, and then map this to actuate different parts of the haptic pajama. Besides that, the hug sensing doll senses varying levels of force acting on it in an accurate and analog manner. The output air actuating pockets applies different levels of pressure to the human body according to the input force. Also, we experimented with color changing cloths to give an indication of distance of separation, and display emotion data of the parent and child.

In addition, our pilot study using psycho-physiological methods shows that there are no significant differences in certain aspects in comparing effects of mediated touch using our system versus real physical touch from a friend to a human participant. This is encouraging as it shows that we are able to elicit the same response from the human in remote mediated touch as compared to real physical touch.

On top of that, we conducted an initial user survey in order to obtain users feedback on usability issues as well as to obtain pointers to guide improvements to be made to the system. It is also encouraging that all users mentioned an increase in the sense of presence when using our system.

This chapter has been organized as follows: In Sect. 7.2, we give a review on the importance of touch communication from psychological and neurological perspectives. We also briefly discuss previous work in the areas of touch sensing and reproduction. In Sect. 7.3, we explain the technical parts of our system. This section is divided into a few major parts of the system including the input touch sensing module, the haptic output reproduction module and the thermal controlled fabric display. In this section, we also discuss the design of user experiments conducted on our system. In Sect. 7.4, we describe and discuss the results pertaining to the technical modules, as well as the user experiments conducted. In Sect. 7.5, we provide a conclusion and future works to the chapter.

7.2 Background

7.2.1 Why Touch Communication?

Touch is a very important way of communication both in animals and in humans. Research in infants suggests a positive correlation between mother touch and gross motor development [47]. This is paralleled by research in non-human animals that revealed epigenetic effects of maternal licking. Offspring of highly-licking mothers has a greater number of glucosteroid receptors in the hippocampus supporting the down regulation of HPA activity during stress [30]. As a consequence these animals are better adapted to deal with stressors later in life. Interestingly, maternal licking also affects the oxytocin system leading to a higher expression of oxytocin receptors in the brain and increasing pro-social behavior in the developing animal [7].

Attachment theory provides a descriptive and explanatory framework for understanding human interpersonal relationships [5]. According to attachment theorists, children and infants require a secure relationship with adult caregivers in order for normal emotional development. The theory originating from earlier ethological experiments on infant rhesus monkeys by Harry Harlow indicated that the infants spent more time with soft mother-like dummies that offered no food than they did with dummies that provided a food source but were less pleasant to touch [8]. Thus, from its origins to the present day, attachment theory suggests that touch is a crucial element in establishing a secure connection between parent and child [48]. There has been much discussion regarding whether or not computers might facilitate remote touch, however, the beneficial effects of mediated social touch are usually only assumed, and have not yet been submitted to empirical scrutiny.

Modern studies of human infants also revealed that the absence of affectionate touch can cause social problems and even lead to premature death [15]. Children who are deprived of maternal contact for six months or more behaved in a withdrawn, depressed and disinterested manner, and were unable to reestablish their normal attachment to their mother. According to Bowlby [5], children who suffer long-term or repeated separations during the first three years of life are usually permanently disabled. These studies suggest that children need to constantly be in touch with their parents. We focus on the interaction between parent and young children because young children are at a formative age in life in which they require a considerable amount of attention and affection. One of the more important acts of showing affection to young children is hugging. Hugging and touching is a vital part of human brain communication essential for the mental development of young children [19]. Young children may not fully understand words, but a hug is a natural and intuitive way to communicate feelings of care to young children. Infants who are unable to speak, communicate through touch and through variations in infant touch across periods research suggest that they communicate their affective states through touch [33]. Through hugging and touching, we can transcend spoken language to the language of wider expression and inner feeling. Some researchers argue that maternal touch can compensate for the lack of verbal and facial emotional communication by depressed mothers with their infants [35]. In the various types of hugs, we may speak of security, confidence, trust and sharing in a manner that no word can tell. Hugging is therefore an important interaction between parent and child. The main motivation for our research using mediated touch and hugs as part of the communication process is to better support social interaction. Processing haptic information is an important function of Parietal Cortex of the brain and plays a significant role in the cognitive aspect of the human's daily activities. This has been shown in various psychological studies exploring how touch is essential for complex sensory–motor tasks while also offering a deeper neural sensation evoking recognition and judgment processes. Such neurological consciousness aroused through the available haptic information is important for humans in decision-making pertaining to their surrounding environment and for interaction with others [24]. Furthermore, it has been shown in the proprioception (a process of correlation amongst the multimodal sensations) of the Parietal Cortex, that the human perception can be influenced to create an illusion of something which is unreal. In [4], a touch is reproduced with the right representation (for example, a rubber hand in place of a real hand), and human subjects are made to believe that the rubber hand is actually real. This cycle of self-attribution convinces the human subjects that a real hand is touching them. This gives us confidence to believe that with the right haptic feel and with the context of the situation carefully controlled and delivered for the human subject, mediated touch communication could be an effective communication channel.

Even though remote textual, visual and audio communication tools exist, remote haptic communication systems serving remote contact comfort for parents and their young children are still sorely lacking. Also, with the busy lifestyle of modern working families, there are fewer opportunities for parents to provide contact comfort for their children. We therefore believe that contact comfort, albeit remote and mediated, can contribute to healthy emotional development between parents and children compared to the situation where there is no contact due to physical separation.

In order to address this issue, we find it necessary to develop a novel interactive system that allows for humans to communicate remotely through touch and other forms of physical contact. Fallman [14] described this process as "Design-oriented Research", where to find new knowledge related to mediated touch, we need to develop a system or tool with which we can study the mediated touch phenomena. The knowledge that we obtain from studies conducted on the use of the system would then serve as further guideline to design effective mediated touch communication system.

7.2.2 Previous Work

In this section, we focus on related and previous works relating to two main aspects of this project, the input sensing and the output haptic systems.

Haptics has been an exciting research topic for many years spanning many different fields. Haptics in communication has been an emerging field gaining much attention with increased applications. MIT Media Lab's inTouch [6] can be considered of one the building blocks of such haptic communication which provides a haptic channel for interpersonal communication. One noteworthy point in is that the focus of this project was not to simulate the real physical forms of haptic gestures in communication but rather to create a physical link for gestures and movements. However, Brave [6] lists down some early closely related haptic communication research such as Denta Dentata [6] a single bit hand holding device. Using robotic physical avatars as the medium for haptic communication the RobotPHONE [41] in 2001 presented a comforting robotic user interface that synchronizes each other's motions and toy positions when connected remotely. These 'shape sharing' robots are held by the users in separate locations. When the limbs or head of one robot is moved, the other robot reproduces the movement in real time, allowing the users to feel the movement as a shared object, thus enabling haptic communication. Similar to this concept PlayPals [2] introduced wireless figurines that enable haptic communication in a playful manner. This project was mainly aimed for children and uses shape sharing doll-like robots to attain haptic communication. In Moving Pictures: Looking Out/Looking In [45], the authors present a tangible multi-user environment that enables and encourages the sharing and manipulation of video content with others. In review of such work, it is clear that these are more focused on the context of haptics and in providing a haptic channel for communication. But in the case of our work, we are more oriented towards enabling realistic, mediated touch, or more specifically hugging in remote communication and understanding the issues that arise in computer mediated touch over a distance.

In a more closely related project, there is some work such as the 'Hug over a distance' [34], 'The Hug' [21], 'TapTap' [3], etc. The 'Hug over a distance' [34] project uses a koala teddy to sense a hug and send it wirelessly to the air inflatable jacket to recreate a hugging feeling. The Koala teddy has a PDA in it of which the screen is touched by the user to send a hug. The PDA on the inflatable jacket upon receiving the hug activates serial controller to simulate the hug. 'The Hug' [21] senses stroking, squeezing and rubbing actions, and connects to another similar remote device which translates the input gestures into light, heat and tactile vibration. Similarly, TapTap [3] is a wearable haptic system that allows nurturing human touch to be recorded, broadcast, and played back for emotional therapy. It too uses tactile vibration embedded clothing accessories such as scarfs to simulate human touch. Cutecircuit's Hug Shirt [9] has detachable pads containing sensors which senses touch pressure, heart beat and warmth, and actuators which reproduces them. This too utilizes vibration actuators to generate the hug. Poultry Internet [30] in 2005 presented a remote human pet interaction system using a jacket specially designed with vibrotactile actuators embedded for pets. These projects indicate the attempts in the past to achieve remote haptics in close relation to hugging. 'TapTap', 'The Hug', the 'Hug Shirt' and Poultry Internet use vibration to provide a sense of a remote hug which does not correspond to the feeling of natural human touch. However, through the Huggy Pajama we attempt to recreate a main property of a hug, the pressure. Even though the 'Hug over a distance' work closely relates to our concept, there isn't sufficient attention given to the pressure level exerted by the inflated jacket. With Huggy Pajama we stress on the importance of regenerating the hugging feeling with accurate pressure levels corresponding to the input force exerted by the sender.

Regarding haptics in clothing, we set out to identify and compare key concepts and technologies relevant to the design space of the Huggy Pajama. Touch Sensitive by MIT Media Lab [44] lists down four different methods they explored for haptic apparel for massage on the move. In one prototype, thermally responsive metallic wires embedded in the apparel caused it to shrink mechanically when a current is passed through. In other prototypes, silicon buttons, vinyl inflatable air pockets and vinyl pockets filled with liquids that diffuse around a wooden ball during a massage were used. In [22], the researchers used a neoprene vest with two arm straps to produce mediated touch. They too used vibrotactile actuators to enable haptic communication and have conducted a study to evaluate the effect of mediated touch. In another project [31], the authors again use vibrotactile units to develop a haptic feedback vest to deliver haptic cues for immersive virtual environments through garments worn on the body. In addition to this, there have been many other examples of wearable haptics used in many applications including tools for aviation pilots [38], way point navigation systems [12], etc. However, many of these systems use vibrotactile actuation to enable haptics. In this project, Huggy Pajama, we stress the accurate reproduction of the pressure in a remote hugging system. As mentioned above, even though some of the systems focused on remote haptic communication, most of them focus on just the context of remote touch, whereas in our project we try to recreate in high fidelity, each hug giving attention to the pressure, which is an essential property of the touch/hug. Even though most of the aforementioned works relate to remote touch, a high number of them use the vibrotactile actuation as a solution to the output haptics generation. Many of them justify this by claiming that it makes the wearable system lighter and more long lasting in terms of the battery life. However, with Huggy Pajama, we employ novel techniques and equipment and use an air actuating system embedded in a jacket to exert exact amounts of pressure on the wearer simulating a realistic hug. We believe that, even though right now it may not be comparable to commercial systems in terms of the usability, this research will open up avenues for more precise communication using haptics in the future, thus enabling more effective communication of feelings.

Shifting attention to sensing technologies, we realize the importance of accurately measuring the haptic properties such as the force of a hug or touch before transmission. Previous works in such research applications have used many different sensing technologies for touch sensing. In 2004, Scott Hudson of CMU's HCI Institute presented some works on LEDs as a touch sensor based on previous works in [28]. However, this system depends on the surrounding lighting conditions in which the sensors are used. In other work related to remote haptic communication, the 'Hug Over a Distance' [34] simply does not sense the force of a hug, thus it simply transmits a command on an execution basis in a binary mode of "on" or "off". Another study demonstrates the usage of capacitive sensors in clothes and accessories enabling touch sensing [27]. The same capacitive sensor technology has been used by the 'Pet Internet' [30] system to sense the touch through sensors embedded in the cute doll. The user's touch characteristics from each petting action on the doll is captured through these sensors and is transmitted via the Internet. However, as we previously stressed, 'Huggy Pajama' is more concerned with the accurate pressure measurement on the input and exertion on the output. Recently, Pressure Profile Systems [36] unveiled their capacitive sensing based tactile pressure sensors [16]. They developed a wearable system, which measures pressure at various spots on a wrist, and were tested out on a professional athlete. There are several other sensor technologies that have been used in tactile sensing which accommodate these qualities. Force sensing resistor or FSR [20] and Quantum Tunneling Composite or QTC [37] are two such methods. CMU's 'Football Engineering' group [18] uses these FSR sensors to accurately measure the player's force on the fingertips and palm when holding the ball. In another very related project, 'The Huggable' by MIT Media lab [43] employs these QTC Sensors for touch sensing on the robot teddy bear. The sensors are embedded behind the silicon gel skin of the teddy and measure force exponentially when the QTC material is deformed. Huggy Pajama uses the latter QTC sensor for accurate pressure measurement. The easy usage and manipulation of the sensor eased through the design and integration phases of the input pressure-sensing module. But the key motivation factor is the accurate pressure measurement suitable for accurate tactile sensing.

7.3 System Description

7.3.1 Mediated Touch Module

The main functionality of the touch device is sensing the location and strength of the touch as input, and then encapsulating and transmitting this data over the Internet and reproducing the force at the receiving end. Thus, it has several electronic hardware modules for each feature.

Input touch sensing module	is used to sense the touch levels and the area of touch of the intended recipient. The pressure variation is sensed by this module, digitized, and this information is transmitted via the Internet.
Output touch actuation module	is used to reproduce the touch levels and positions related to the received digitized data from the input touch system. This module consists of a pneumatic system controlled electronically with air pouch actuators.
Fabric display module	consists of a fabric coated with thermo-chromic ink and a temperature control system made from Peltier (p–n junction) cooling technology. The thermo-chromic ink color is changed according to the different levels of temperature applied.

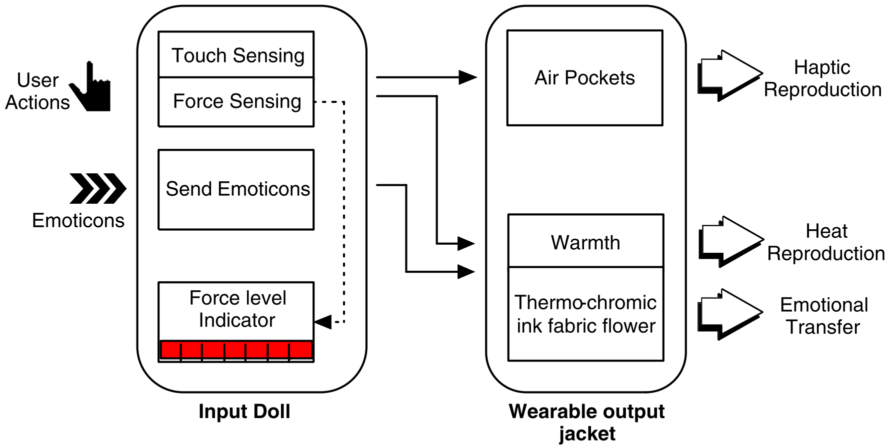

Fig. 7.2 Overall block diagram showing different modules of system

The overall system is a wearable remote hugging jacket which includes all three modules mentioned above. A block diagram of the mediated touch system is shown in Fig. 7.2. Touch sensing, touch reproduction and a color changing module with thermal control modules are connected via the Internet to reproduce real-time touch sensation and affective communication.

This system presents the flexibility for either one-way or two-way communication between the sender and the receiver. For example, the sender (parent) sends a hug to his/her child (receiver), and if parents are at work in a business meeting, it might not be suitable for them to put on the pajama. They can easily hug their child by using only the input device. However, in the case of being in an office, hotel, or airport, the parent could wear the pajama and have two-way hugging with the child.

7.3.1.1 Input Touch Sensing Module

For accurate reproduction of the touch, the input system needs to capture precise and high fidelity touch data of the human touch. Input touch should be close to reproducing the analog effect and thus the current system is capturing 256 levels of pressure variations during an ordinary human touch. The first approach was to use the most common FlexiForce [17] technology based tactile force and pressure sensors. Due to the factors such as high load variation to generate an acceptable output voltage and limited sensing area, these sensors were dismissed and are no longer used.

We conducted tests to determine the normal range of force exerted by a variety of human subjects. We asked participants to apply pressure directly to the doll interface with one hand, using the appropriate amount of force that would symbolize most effectively sending a hug to an intended recipient. This served to give a general understanding of the rough order of magnitude of forces that the input sensing would need to be able to handle.

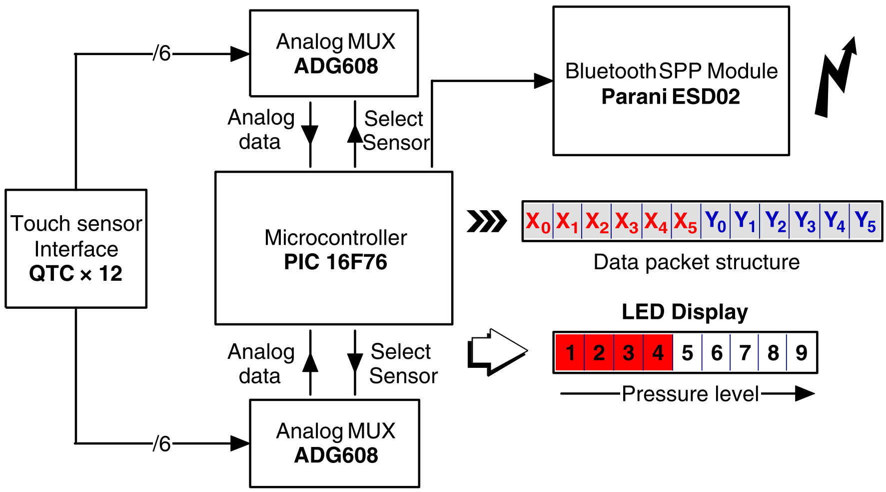

Fig. 7.3 Block diagram of force sensing module

An experiment was conducted on 20 persons of ages between 5 and 35 with an even split of male and female participants. From the experiment, the following results are obtained. We determined that it is sufficient to sense equivalent weight ranging from 0.010 kg to about 2.0 kg for a computer based human touch sensing system. Based on these experimental results, we searched for suitable methods for sensing human touch pressure, and compared their characteristics. An important requirement was that the sensors must be lightweight, small, accurate and suitable for small mobile devices. Matching all these characteristics, QTC [37] based material was used to construct the input sensing module.

QTC-Based Force Sensing Unit We chose the QTC Sheet form factor as it allows flexibility in terms of size and shape. This allowed considerable freedom in designing the sensing component of the input interface. Figure 7.3 shows the circuit design of the input force sensing device and how it connects to the output. The important part here is the QTC sensing circuit.

Figure 7.4 shows the touch and hug sensing device. The aesthetic design is shaped like a small doll with a body and arms along the sides to correspond to the human body where we want to reproduce the haptic sensation. The appearance of the input device is important to consider as this directly affects the user experience in affective communication and the ability to intuitively understand the system image. the system mappings and affordance. There are 12 QTC sensing areas, which cover the front and back of the doll body, as well as both the side arms. The input module operates on 2.4 V, thus a 3.6 V standard Li-ION battery is used with a DC–DC power regulator to reduce the power loss and to increase efficiency.

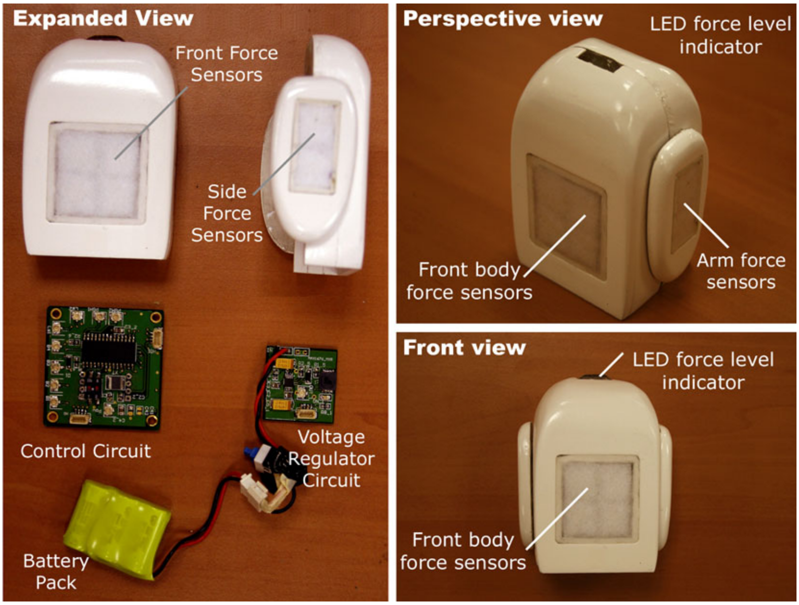

Fig. 7.4 Actual force sensing module based on QTC

7.3.1.2 Output Touch Actuation Module

The output touch actuation system consists of air bags which inflate and deflate according to the remote input while maintaining the pressure in a constant level. Overall remote hugging jacket consists of 12 individual air pouches, which corresponds to each of the 12 sensors on the input doll as shown in Fig. 7.5. Figure 7.6 show the individual air pouch with its controlling air actuation module.

Since the 12 air pouches need to be controlled simultaneously, each should be controlled independently from each other and should have a centralized controlling. The design came up with 12 slave air actuation modules controlled by a master module with I2C interface. Master module receives the multiplexed touch information for all the 12 actuation points from a wireless Internet (WiFi) module. Then master controller decodes the information and distributes to the individual slaves with the pressure level on set value. This modular approach was very useful when operating and troubleshooting the blocks and for easiness of adding more slave modules. Figure 7.7 shows the master module block diagram.

Slave modules control the inflation and deflation of the air pouches with the received touch information to reproduce the computer mediated touch. In the first prototype, we used only one air pump to pump in the air and a electronically controlled solenoid valve for controlling the air exhaust. Initial testing resulted in that the inflation curve and deflation curve with respect to time had a signif-

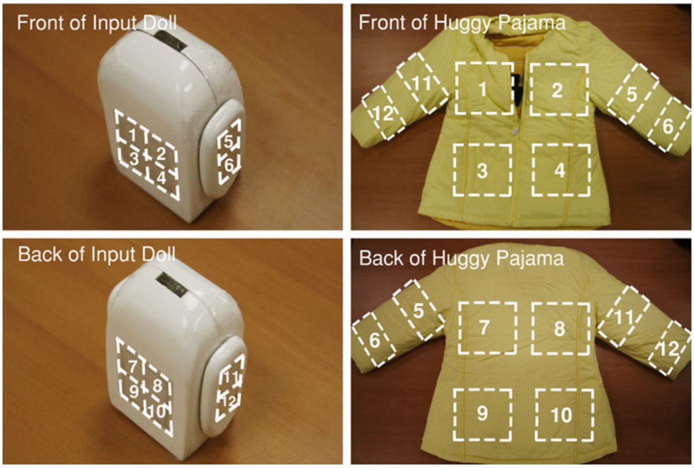

Fig. 7.5 Mapping of input sensors to output actuators

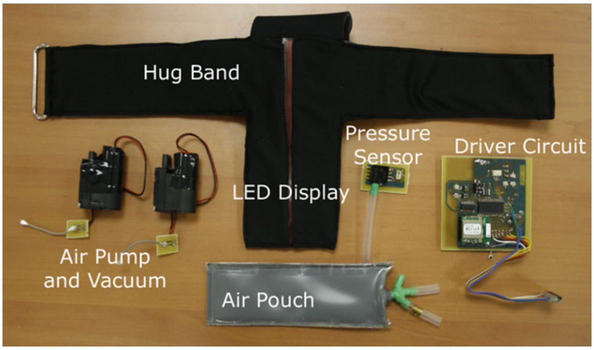

Fig. 7.6 Single module of air actuator system

icant difference; especially the deflation takes much more time compared to inflation. This result was due to natural air flow of the solenoid valve while air input is from an electronic pump. Thus we used an air output pump to pull the air out while deflating and this solved the time lag issue. Such a configuration of two pumps was used to make the system response as fast as possible to the users input (touch sensing). Pumps normally used for medical applications were used, as they are lightweight and of low sound emission. The air pouch pressure is constantly monitored using an air flow pressure sensor attached to the slave module and it feeds the sensor data constantly to the closed loop feedback controller. The module also has a visual indicator indicating the current force level.

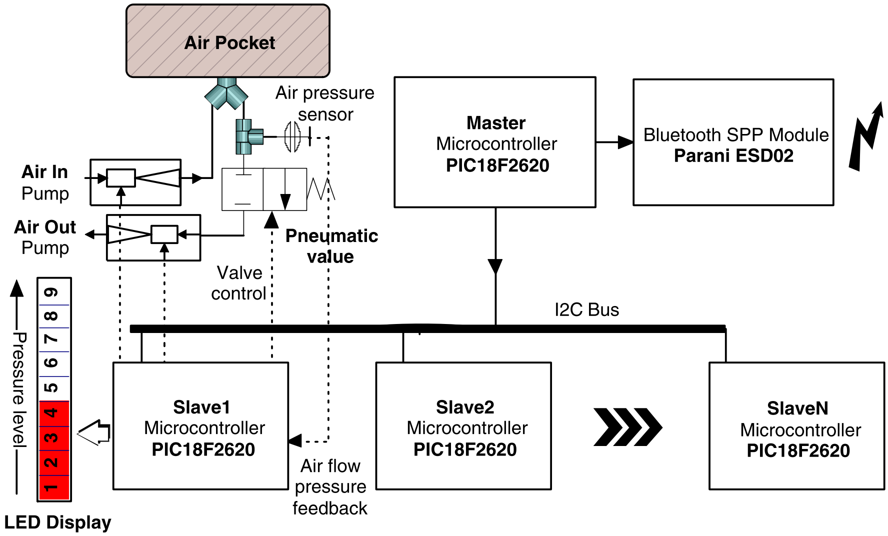

Fig. 7.7 Block diagram for output actuation circuit

Table 7.2 Non-emissive display technologies

Technology	Actuation technique
Piezochromic	Applying pressure
Photochromic	UV light
Electrochromic	Applying charges
Ionochromic	Ions
Halochromic	Change of pH value
Tribochromic	Mechanical friction
Solvatochromic	Solvent polarity
Photochromic ink	UV light
Thermochromic ink	Applying heat

7.3.2 Thermal Controlled Fabric Display

There are several types of methodologies for fabric displaying and all of them are categorized into two major channels, namely emissive displays and non-emissive color changing inks. Many different works have already been carried out even expanding to commercial level products in the emissive fabric displays category such as Lumalive by Phillips [32]. In this study, we are particularly interested in the non-emissive displays due to their more passive and calming appeal to users rather than emissive displays which can be intrusive or of disturbing nature. These non-emissive displays usually change their properties based on external influences as listed down in Table 7.2.

Out of the above, thermochromic ink was selected to be our choice due to its easier implementation, yet more effective results. Thermochromic inks change their color when heat is applied. They are available in a wide range of colors with different activation temperatures. In the next section, we discuss the design and implementation of the temperature controller in order to actuate the thermochromic ink that is painted on the fabric. For this purpose, we use a custom made ink to display several different colors at several different activation temperatures.

7.3.2.1 Temperature Control System

In the same context, a cooling–heating device would be necessary for the color to be changed in the thermochromic ink. The cooling system was essential as the previous system involved only a heater to raise the temperature and relied on natural heat dissipation from the cloth for the temperature to drop down and thus to re-activate the other thermochromic ink colors.

The research work probed into several prevalent cooling systems that were currently employed in various scenarios to find the right one for our use case. High priority was to be given to the one that came in smaller size and hence ensured mobility for the pajama. It was important to have a cooling system that was low on power consumption as the system was to be powered by batteries that were on-board the pajama. Since the pajama was to be worn by a child, it was important to ensure that there were no moving parts and required little or no maintenance. For the same reason, the system could bear no hazardous materials of any form that might harm the child's health or constrain his or her natural movement. With the above described parameters in mind and considering the size of the modules and controllability, the Thermo-Electric Temperature control system was selected and implemented in the thermal controlled fabric display.

7.3.2.2 Thermo-Electric Temperature Control System

Thermo-electric temperature control systems allow cooling below ambient temperature, but unlike other cooling systems that allow this (vapor phase refrigeration), they are less expensive and more compact. Peltier elements are solid-state devices with no moving parts; they are extremely reliable and do not require any maintenance.

Our thermo-electric temperature control system uses one Peltier module as a cooling and heating device by electronically changing the current flowing direction as outlined in Fig. 7.8. Since the p–n junction current is much higher in Peltier modules, the system should be capable of handling a large flow current. When the system is in the cooling cycle, the cooling surface becomes very cold, and according to the energy conservation theory, the other surface becomes hot. In order to maintain the stability, we use a proper heat sink to effectively transfer the heat to ambient environment and cool down the hot surface. When the system is in the hot cycle,

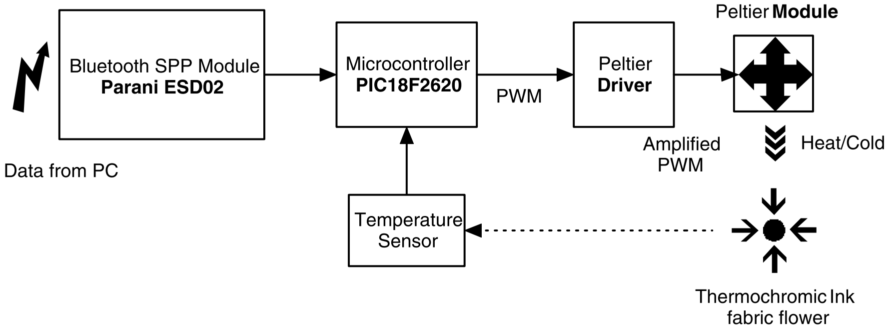

Fig. 7.8 Actual input force causing different pressures on the arm of the user

previously cooled surface is now getting hot, while the other surface is getting cool. This also automatically helps to fast cool down the previously heated surface.

The voltage to the Peltier module is controlled using a pulse width modulated voltage signal. Thus it changes the current flowing through the module under a constant resistance at constant ambient temperature.

In order to obtain greater stability, the system includes a PI controller in the closed loop control system. A PI controller with proportional (Kp) and integral (Ki) coefficients was selected based on the nature of the responses obtained from the initial system.

7.3.3 Design of Experiments

7.3.3.1 Quantitative Study

In addition to creating a remote communication system that senses and reproduces the soft, natural touch and hug, we compared the effects of such reproduced remote touch to actual physical touch. This study is grounded in psysho-physiological theory [11, 49], and the objective is to provide further motivate that a remote touch system can have the same effect on humans compared to a real physical touch.

More specifically, the present study aims at studying the effects of a mediated touch as compared to a real touch. In the mediated touch, we are mainly focusing on the pressure and contact feeling from the many components that make up a touch. For example, we are interested in whether it is the knowledge that someone is touching you rather than the actual body contact that is soothing. If true, one may envision the application of remote touch devices such as the Huggy Pajama. Furthermore, by measuring brain responses and cardiovascular changes we may uncover the neuronal and psycho-physiological mechanisms that mediate positive effects of touch. We have shown how previous psychological studies have shown the importance of touch, especially to the parent–child relationship. However, very few studies of such kind relate to mediated touch. We would like to find out whether it is possible to transmit some kind of physical touch and reproduce it as mediated touch. This study would give support to our Huggy Pajama system, and also for any related works by other researchers in the future.

In a previous work [39], researchers have shown that surface stimuli can elicit or excite some kind of emotional or cognitive response from humans. In the same vein but with a significantly different purpose and to explore in a more in depth manner, we are comparing human–human communication through physical and mediated touch. We would like to find out the kind of emotional response that can be reproduced through mediated touch and real touch, and therefore set the ground for future research on developing mediated touch communication systems. More importantly for this research, we wish to determine if there is a significant difference in emotional response between physical and mediated touch. If there is no significant difference then this would hold significant confidence for designers of remote and mediated touch systems that they can effectively design such interactive systems to simulate the effect of physical touch.

In a pilot study, we compared heart rate responses to emotional challenge across three conditions: participant alone, participant in the company of a friend without touch of any kind, human touch by a friend. Already the company of the friend reduced heart rate responses, and a further reduction of heart rate in the touch condition was non-significant. This suggests that the perceived closeness to a friend modulates physiological arousal, and that touch may add only little to the comforting effect of the presence of a friend. However, touch clearly represents an extreme form of closeness and thus 'virtual touch' created by the remote mediated touch device may overcome the perceived distance to a friend and reduce physiological arousal without that friend having to be present.

The present study aims at investigating the effect of touch on current emotional state. To this end, adult dyads will be invited to the lab. Dyads are simply defined as pairs of people. They will be exposed to visual and auditory sounds of emotional and neutral valence. The important questions that we want to address are:

1. How does mediated touch have an effect on humans?
2. How important is the context of touch in mediated touch scenario?
3. What is the difference in the results of these experiments for physical touch and mediated touch?

For this purpose, a prototype of a pressure armband actuated by air was built, which is a hardware module of our present Huggy Pajama system, but modified to specifically conduct the laboratory experiments detailed below. To conduct the experiment according to the above framework of questions, we first detail the hypothesis of the experiments. Our hypothesis is that computer mediated touch has no difference with real touch in terms of touch sensation, warmth and trust. Human touch is an important means of which humans communicate with each other. Human touch has effects on a person's emotional state and sense of well being that are cognitively mediated. Since the Huggy Pajama is offered as a surrogate to the direct beneficial effects of human touch, this experiment is designed to compare the effects of a Huggy Pajama prototype with that of direct human touch in situations of varying degrees of physiological arousal.

Experiment Setup This experiment will involve two females. One will be the participant, and her friend will accompany her for real touching and sending hugging signals. We are using 64 active electrodes with the help of a head cap on the participant to get the EEG data. Precautionary steps like removing all metallic parts inside the EEG room has been done to reduce the noise level.

In the touch sensing part, QTC touch sensors are used to get an accurate linear touch sensing information. Real time touch data is plotted in the experiment setup room PC and it monitors the touch/no touch threshold values. As for the output actuation part, an armband is gently wrapped on the participant's arm, and this armband is slightly lifted by a rope hanging from the ceiling to prevent the weight of the armband resting on the participant's arm.

Participants Description Since females are normally sensitive and more aroused to fear and happiness, we have selected female participant for the user testing. All participants were accompanied by a close female friend. The friendships had an average duration of 20.8 months (S.D. = 27.6). Participants were asked to rate how close they felt in their relationship towards their friend on a 7-point closeness scale ranging from 0 (not close at all) to 7 (very close). The obtained closeness scores averaged to 4.67.

Nine young women and their female friends participated in this study. The participants ranged in age from 19 to 27 years and they had normal or corrected to normal vision. None reported auditory perception deficits or psychological disorders.

Procedure Participants were seated in a comfortable chair facing a computer monitor at a distance of 0.8 m. They were told that they would see a sequence of pictures and that they should simply attend to those pictures. The experiment consists of three blocks of trials during which the seated participant will view pictures presented serially onto a computer screen. The pictures will be either emotionally unpleasant and highly arousing, or neutral in valence and low in arousal. These pictures (60 emotional and 60 neutral per block) are taken from two standardized and validated databases of pictures (IAPS and Ekman). The presentation of these pictures will be pseudo-randomized. The three blocks are shown in Fig. 7.9.

1. *Friend (touch/no touch) block*. Here the friend is seated next to the participant, with a curtain separating them so that there is no visual contact. The participant will be viewing a monitor and the friend will plug in headphones which will present the visual and auditory signals and stimuli. Specifically, the friend will not see the pictures presented to the participant, and the participant will not hear any instructions given to the friend. The participant will be instructed that during some trials, his/her friend will be touching the participant's forearm. During some trials of picture presentation (touch trial), the friend will be instructed to touch the participant. Once the friend touches, the pictures will be presented to the participant. After each such trial, the friend will be instructed to remove the touch by a beep signal. After the friend removes touch, the next picture is presented. During the other trials, the friend will not be given instructions to touch the participant (No-Touch trial). The Touch and No-Touch trials will be presented in a pseudo-randomized order. The timing of the trials is outlined in Fig. 7.10.

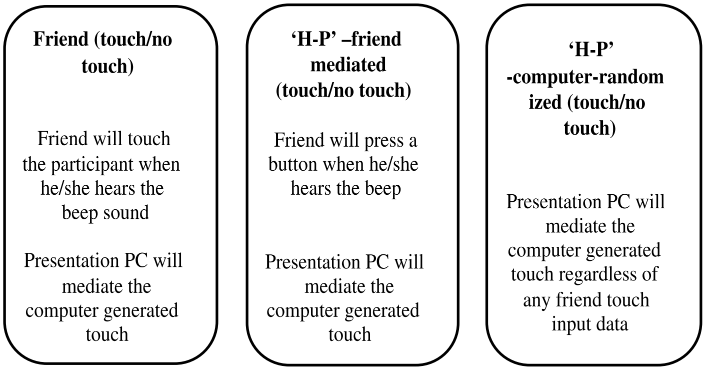

Fig. 7.9 Three different blocks of user experiments

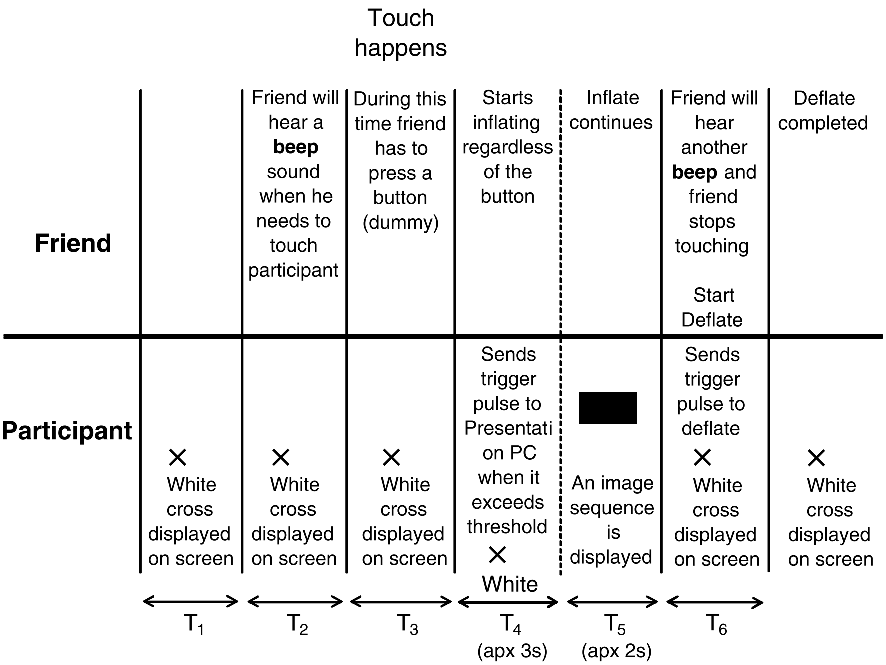

Fig. 7.10 Timeline of events for user experiment

2. *Huggy Pajama–friend mediated (touch/no touch) block*. In this block, there will be a Huggy Pajama prototype armband attached to the participants forearm. The participant will be instructed that this armband will be inflated during some trials by his/her friend. The friend will be seated outside the room and will be listening to the audio instructions from the headphones. This should enhance the physical separation between friend and participant, which would mimic the real-life

conditions under which the armband is supposed to function. Again, the ‘touch’ and ‘no-touch’ conditions will be presented in a pseudo-random order as before. In the touch conditions, the friend will press a button to inflate the armband. To reduce performance errors and time-differences between the friend block and Huggy Pajama blocks, the actual inflation will be started by the program during the specific ‘touch’ trial regardless of the time-delay of friend’s button-press. In the no-touch condition, the armband will be in a deflated state.

3. *Huggy Pajama–computer randomized (touch/no touch) block*. The conditions are all as before. The participant will be instructed that during some trials, the Huggy Pajama prototype armband device will inflate in a random fashion determined by a computer program. This block will verify out whether the changes in the dependent variables depend on tactile stimulation only or are due to the participant’s attribution of the source of Huggy Pajama touch.

The EEG was recorded from 64 electrodes mounted in an elastic cap according to the modified 10–20 system. The electro-oculogram (EOG) was recorded using four electrodes, which were attached above and below the right eye and at the outer canthus of each eye. Additionally, one recording electrode was placed on the nose tip. The data were recorded reference free using the ActiveTwo system from Biosemi with a 256 Hz sampling rate.

Preceding the experimental blocks, a practice block was carried out. In this block, the friend was instructed on how to carry out the touch. He or she was asked to place his hand on the participant’s forearm with the upper part of his palm touching the pressure sensor. Pressure values of 20 successive touch trials were recorded and analyzed subsequently for mean and standard deviation (sdv). These values will be used to adjust the pressure of the Huggy Pajama armband (the pressure had to randomly reach a value within the sdv range such that the armband pressure mean matches the friend touch pressure). The temporal delay between the touch cue and the touch execution was used to adjust the temporal delay between fixation cross onset and picture in the no-touch trials and the Huggy Pajama touch trials.

During the experimental blocks, we monitored brain activity as well as gathered peripheral physiological measures such as heart-rate. These will be the dependent variables that we will analyze for differences in a 3(friend/h–p/computer blocks) $\times$ 2(touch/no-touch) $\times$ (emotional/neutral) within-subjects design.

Data Analysis EEG data were processed with EEGLab [10]. The scalp recordings were re-referenced against the nose recording and a 0.5 to 20 Hz bandpass filter was applied. The continuous data were epoched and baseline corrected using a 150 ms pre-stimulus baseline and a 1,000 ms time window starting from stimulus onset. Non-typical artifactual epochs caused by drifts or muscle movements were rejected automatically. Infomax, an independent component analysis algorithm implemented in EEGLab, was applied to the remaining data and components reflecting typical artifacts (i.e., horizontal and vertical eye movements) were removed. Back-projected single trials were screened visually for residual artifacts.

7.3.3.2 Qualitative Study

In addition to the psychology experiment to compare the effects of mediated touch with real touch, we conducted a user survey. The purpose of the user survey is to gather user feedback on Huggy Pajama to investigate usability problems and also to guide future design of our system. In our survey, ten (10) pairs of participants of the parent–child relation were engaged. The verbal and behavioral feedback from the user sessions were analyzed to acquire a detailed understanding of the needs, wants and tasks expected of Huggy Pajama. The main methods of our approach used here are through observation, survey questionnaire and interview.

Each session lasted approximately one hour. Initial questions focused on the participants backgrounds, behavioral practices, context of usage and usability. The user behaviors have been observed and recorded throughout the whole experiment. Questions related to their computer proficiency, how often they hug and spend with each other were asked. This was done to assist in the interpretation of observed behavior during analyses. This was followed by a period during which the participants were asked to perform a few tasks based on the given scenario. After having used and commented on the functionalities, participants were asked to rate them on a Likert scale. The session also includes open-ended questions for further analysis that can guide future iterations of the design of our system.

After conducting the experiment, results were gathered and analyzed. In our study, the empirical measurements obtained from the experiment were able to facilitate the understanding of users needs, wants and usability problems of Huggy Pajama and be used as a form of feedback to guide the design of haptic communication system. After the analysis, we can understand if users achieve their intended goals. For example, Huggy Pajama is able to improve the sense of presence among the paired users. On top of that, sub-goals such as finding alternative means to express ones concern and to make one feel better during communication can also been identified. The potential users and the context of use of Huggy Pajama can range from parents with young children in the childcare center to parents of young adults who are going overseas for an exchange program, and this user survey can identify them.

7.4 Results and Discussion

7.4.1 Input Touch Sensing Module

The input touch sensing device that we developed exhibit satisfactory characteristic for our purpose. We manage to embed the flexible QTC sensors into a small and mobile doll design which promotes mobility for users.

Figure 7.11 presents the actual measurement of the output signal from two sensor samples (labeled Sample 1 and Sample 2), which exhibits an almost linear characteristic from 0 to 6 newton (N) of input. When the input increases from 6 N, the

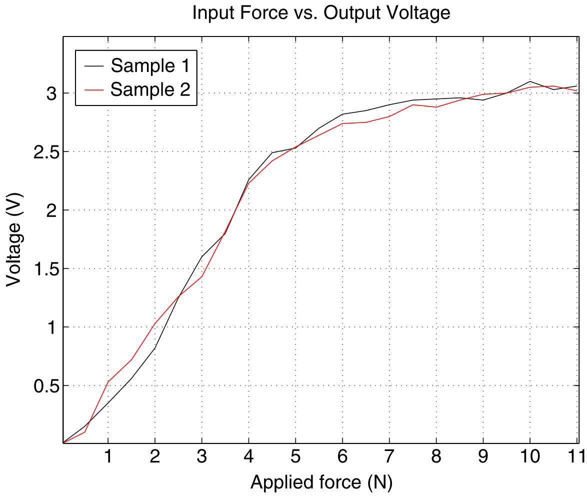

Fig. 7.11 Output voltage vs. input force for force sensing module

sensor enters the saturation region. As stated in the QTC characteristics this was due to being reaching the minimum resistance in the QTC sensor and explains more from the force vs. resistance characteristics of the QTC. It also shows a very consistent output pattern from the two samples. This indicates a good reproducibility of the design.

7.4.2 Output Touch Actuation Module

We describe the response characteristics of the output air actuation module that we developed which reproduces touch and hug.

Figure 7.12 shows the step response at a rising edge of a input signal. Rise time = 2.3 s, Settling time = 4.3 s, and Percentage error = 6.25% are the important characteristics of the step response. According to the calculated values, the system is able to stabilize at the settling point for a step rise input.

Figure 7.13 shows the step response at a falling edge of an input signal. Fall time = 1 s, Settling time = 4.2 s, and Percentage error = 5% are the important characteristics of the step response. According to the calculated values, the system is able to stabilize at the settling point for a step fall input.

The use of two pump configuration is justified here. In contrast, if the air was released under natural atmospheric pressure to lower the pressure in the air pouch, the response would be too slow.

The static response of the system is shown in Fig. 7.14. The graph shows the pressure input to the system (sensed pressure data) and the output created by the air actuator system. The graph implies a linear relationship between the input and the output pressure.

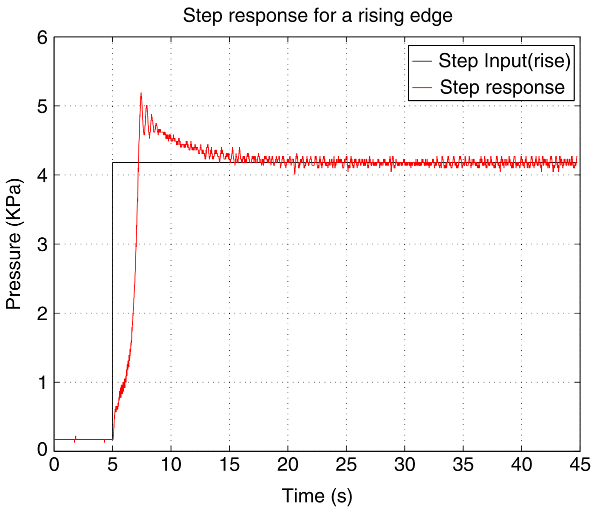

Fig. 7.12 Step response at a rising edge of an input signal

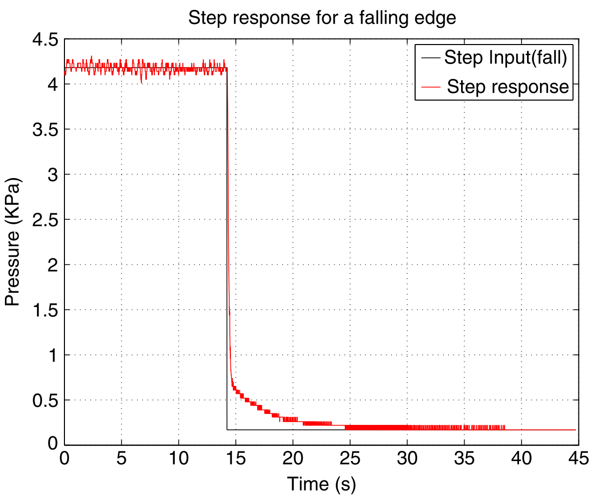

Fig. 7.13 Step response at a falling edge of an input signal

The impulse response of the system is shown in Fig. 7.15. This ensures that the stability of the system to the external sudden disturbances. The system responses with a heavy damp and re-stabilize very quickly for a impulse input.

In order to show the PI controller is working for full span of the pressure variations, we conducted a step response for 6 different pressure level changes. According to the graphs in Fig. 7.16, it shows that the system is capable of obtaining and achieving the given set point within a few seconds.

Figure 7.17 shows the arm band version of the first prototype where user applying a force to the input device which is the design with a doll exterior being tested in the form of an armband. Also shown is the corresponding state of the air actuating output module. The red LEDs function as a visual feedback on the relative amount of

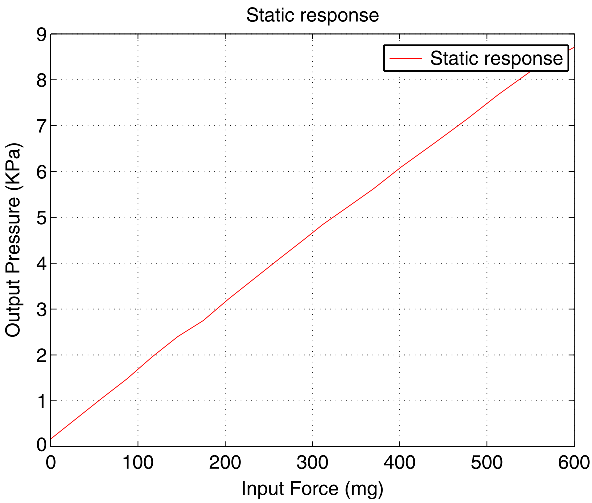

Fig. 7.14 Static response of output actuation module

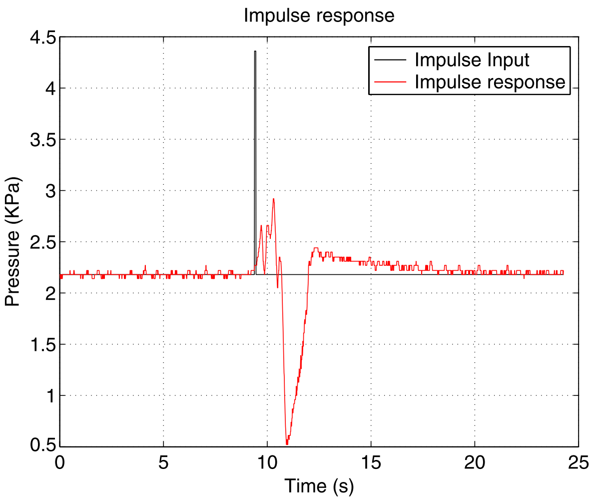

Fig. 7.15 Impulse response of output actuation module

force being applied by user. Initially, when no force is applied, the air output module is at normal atmospheric pressure, and the LEDs are not activated. As the force on the input device increases, the air output module applies increasing pressure on the human arm. This is achieved by pumping air into the air pouch until the pressure feedback sensor shows the desired pressure.

The above showed one output module being tested in the form of an armband. In the Huggy Pajama system, there are 12 unique input sensors which correspond to 12 unique output modules. These 12 output modules are integrated into a pajama for the children. Currently, as the result is a prototype with the need to fit all modules, we integrate them into a more sturdy soft jacket-like construction. Figure 7.18 shows the Huggy Pajama actual prototype in action.

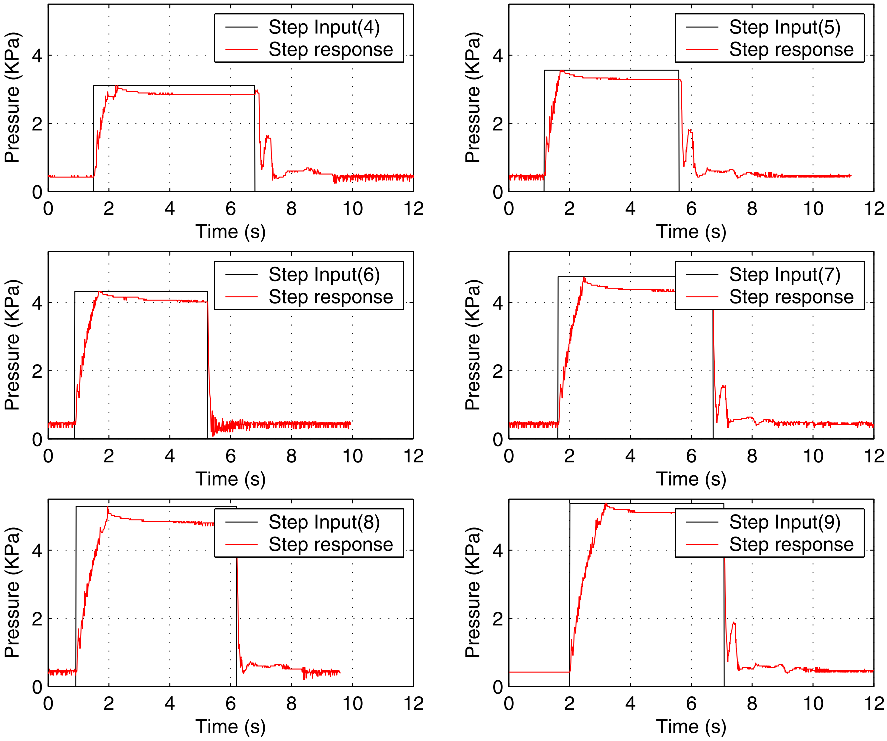

Fig. 7.16 Step responses for 6 different level variations of output actuation module

Fig. 7.17 Actual input force causing different pressures on the arm of the user

Fig. 7.18 Huggy Pajama system overview

7.4.3 Thermal Control System

Here, we describe the response characteristics of the thermal control system that we developed.

According to the data gathered during the tuning of the PI controller, Ki=0.1 and Kp=20 were selected as offering good stability.

The plot in Fig. 7.19 shows the steady state response of the Peltier cooling module with the fine tuned PI controller. In this configuration (Kp=20, Ki=0.1), Rise time = 3 s, Settling time = 4 s, and Percentage error = 1.43% are the important characteristics of the example step response. According to the calculated values, the system is able to stabilize at the settling point for a step rise input.

The plot in Fig. 7.20 shows the linear relationship between set point and steady state response of our temperature control module. The test were carried out from 15°C to 45°C and within that range the maximum percentage error reported was 7.58%.

Color Changing Fabric Display From the concept of embedding the color change into the design of Huggy Pajama, we have an interface that allows expression of feelings and moods. The thermal control system developed allowed us to achieve a good control of color to display using thermochromic ink on the fabric.

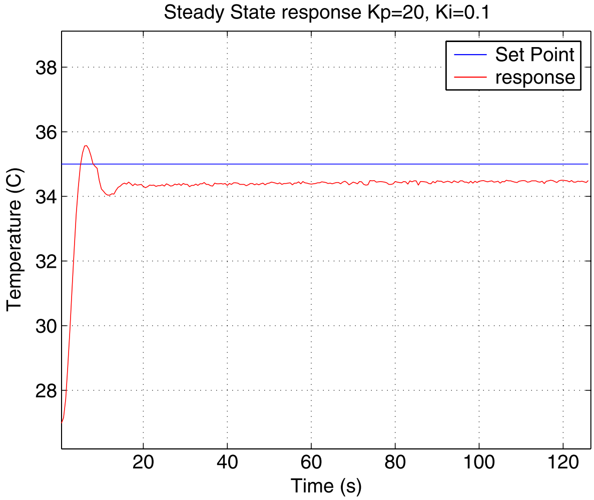

Fig. 7.19 Response with Ki=0.1 and Kp=20, steady state error=1.43%

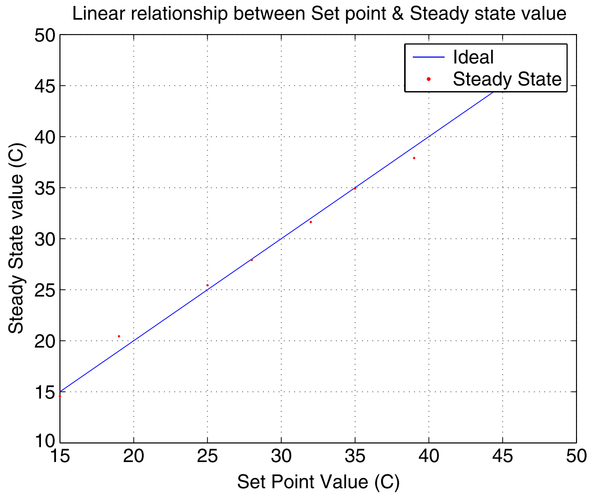

Fig. 7.20 Linear relationship between set point and steady state response

We can customize different designs to suit the wearer. For example, young children can have color changing emotion expressing teddy bears appearing as patterns on their clothes. One example, which we implemented, shows a flower pattern embedded into the printed pattern on the Huggy Pajama in Fig. 7.21(a). Initially, the flower pattern is not visible.

As the parent communicates his/her feelings to the child, the flower pattern gradually appears. This is caused by the control of the thermochromic ink using conductive yarn. As the thermochromic ink is heated, it reveals the flower pattern, and the ink becomes transparent upon fully reaching the activation temperature.

In another example, a flower fashion accessory is designed for a young child in Fig. 7.21(b). This flower accessory thus becomes more than just an accessory, it is

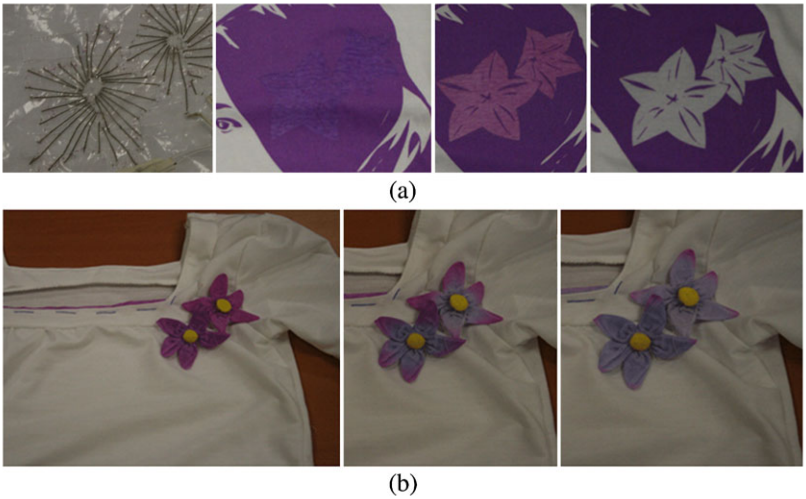

Fig. 7.21 Color changing flower pattern design as cute, emotional interfaces for Huggy Pajama. From *left* to *right*: (**a**) a close-up of girl figure, thermochromic ink being heated reveals flower pattern (indigo to light blue); (**b**) color flower accessories attached to pajama

a connection point between the parent and the child. It allows the parent to relate his/her feelings to the child, and the child to see the feelings. The flowers reveal intermediate and fully changed color upon changes in the controlled temperature. These color changing design and accessories are cute and emotional interfaces for Huggy Pajama.

7.4.4 Evaluation of System

7.4.4.1 Quantitative Study

An ANOVA method is used with Block (friend-physical-touch, friend-remote-touch, computer-remote-touch), Touch (yes, no), Emotion (Emotional/Neutral), Region (Anterior/Middle/Posterior), and Laterality (Left, Right) as repeated measures factors.

When looking at overall data across blocks, we detect there are no significant differences between the 3 different blocks. While this did not show definitively that mediated touch is exactly equivalent to real touch, it gives reason for a conclusion of a relative equivalence. The effect of the touch was not qualified by the mode of touch. In other words, the mediated touch had the quality of the other modes of touch.

On the other hand, we also compared the touch (neutral vs emotional pictures) vs no-touch (neutral vs emotional). P3 works in response to target stimuli which are stimuli that have some relevance to the participants. In the touch (neutral/emotional)

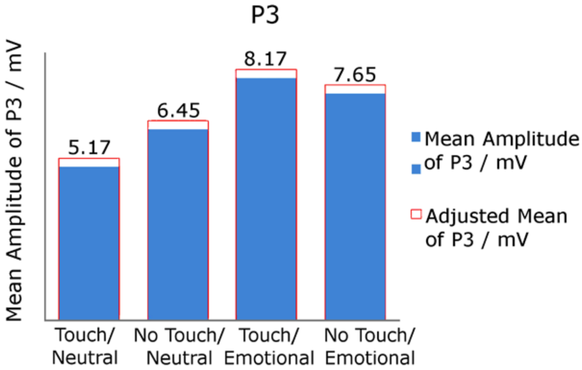

Fig. 7.22 Statistical results for electrode P3

condition, we see a significant difference, while in the no-touch condition, this difference is not statistically significant, which implies that touch actually enhanced the emotion effect.

The EEG reflects synchronous neural activity primarily from cortical regions. One can derive an event-related potential (ERP) by averaging the recorded EEG signal over a class of similar events (e.g., negative pictures). By averaging, random brain activity unrelated to processing this class of events will be reduced whereas brain activity associated with processing this class of events will be amplified. Past research has indicated that the ERP obtained in response to pictures shows a characteristic series of positive and negative deflections. In particular, a positive deflection peaking at around 300 ms following stimulus onset, the P3, has been consistently linked to emotional processing. Specifically, in numerous studies, it has been shown that emotionally provoking pictures elicit a larger P3 than neutral pictures [29, 40]. Based on this and other evidence, researchers have concluded that it reflects the attention captured by an event. As such, P3 gives an indication of whether negative pictures are equally attention capturing when presented in conjunction with the three touch conditions. As P3 is a reflection of attention, it could mean that people feel safe during touch and thus are comfortable to attend more closely to the negative pictures.

Event-related potentials derived by averaging data epochs for each condition revealed a negativity around 200 ms followed by a positivity (P3) around 400 ms following stimulus onset. The factors Region and Laterality comprised the following subgroups of electrodes: anterior-left: AF7 F5 FC5 C5; anterior-middle: AFZ FZ FCZ CZ; anterior-right: AF8 F6 FC6 C6; posterior-left: CP5 P5 PO7 O1; posterior-middle: CPZ PZ POZ OZ; posterior-right: CP6 P6 PO8 O2. This selection of electrodes ensured that the tested subgroups contained equal numbers of electrodes, while providing a broad scalp coverage that enabled assessment of laterally and centrally distributed effects.

Looking at the graph of P3 (Fig. 7.22), the analysis of mean P3 amplitudes revealed a Touch by Emotion interaction ($F[1,8] = 7.58$, $p < 0.05$). The follow-up analysis indicated that the Emotion effect was significant during tactile stimulation ($F[1,8] = 21.6$, $p < 0.01$) but not significant during trials without tactile stimulation ($F[1,8] = 2.53,\ p > 0.05$). This implies that touch actually enhanced the emotion effect irrespective of where the touch originated.

Our results did not show any significant differences among the three touch conditions. The findings suggest that there is relative equivalence in certain aspects of the different touches (friend-physical-touch, friend-remote-touch and computer-remote-touch) based on EEG data. This is promising for work in remote mediated touch systems in that we might be able to represent or reproduce a physical touch remotely and achieve the same feeling in humans, and perhaps comparable to when they are physically touching each other.

Also, the results show that touch actually enhanced the emotion effect across all three touch conditions, compared to the no-touch case. This suggest that even in the remote mediated touch scenario, we are able to elicit heightened emotional response from the participants. While still at a preliminary stage, this result shows that remote mediated touch might enhance the emotion effect in the same manner that actual physical touch can.

Generally, we are encouraged by the results which, though did not fully follow our expectations in terms of arousal response, supported the research in the area of remote mediated touch for communication. Though we cannot yet make absolutely concrete claims that remote mediated touch can be a direct substitute for real physical touch, it nevertheless gives some scientifically positive indication for its use in such scenario. To the best of our knowledge, this is the first time an in-depth analysis from a psychological perspective is undertaken to study the effects of remote mediated touch compared to real touch on human participants.

There are a few limitations for the study conducted. The data is based on 9 female participants. With data from more subjects, we may be able to see clearer results showing significance. Also, additional types of data can be obtained and analyzed, for example, heart rate and brain fMRI.

Furthermore in this study, we are looking at the effects of touch based on short term events. In the future, we could explore other lengths of events that lead to a touch. Additionally, we could also add other aspects of touch such as texture, temperature, and moisture.

7.4.4.2 Qualitative Study

Huggy Pajama is able to improve the sense of presence among the paired users. On top of that, users also found Huggy Pajama useful in expressing one's concern for the remote person and in making the remote person feel better emotionally during remote communication sessions.

From user feedback, there was confirmation that the prototype is useful for improving the sense of presence of loved one and easy to handle. All of the users find that learning how to use Huggy Pajama is either easy or very easy. None of the users felt that it is hard to remember how to activate the system and only 20% of the users asked for help from the facilitators during the period of use. All of the respondents reported encountering no difficulties in using the system.

Most of the users who participated in the experiment have positive feelings about Huggy Pajama, and 90% felt that Huggy Pajamas is useful in helping them to improve the sense of presence of the loved one (rated 4 or 5 on the Likert Scale). A significant 70% felt that the system could help to improve their relationships among loved ones. Some other benefits stated by users include improving remote communication, achieving a better way of expressing concern, and simply making the other party feel better. The results also show that age, gender and computer literacy do not have significant impacts on the users interaction with Huggy Pajama.

Responses from the questions regarding projected use of the system, positive confirmation of the wide use for emotional communication was represented. As an example, all respondents would recommend Huggy Pajama to a friend whose child is going abroad for an extended time. As such, we can deduce that the most appropriate context for use of Huggy Pajama is when loved ones are separated over a period of time. The next most favorable context of use was for the scenario of a parent with a child in childcare, showing that typical working parents with young children could be potential key users of such a communication tool.

A majority of the users responded that the Huggy Pajama feels convincingly like a hug shared in real time. For both parents and children, 80% of them felt that it gave a realistic feel of hugging and being hugged. The children from our participants were generally satisfied with the pressure of the hug from the Huggy Pajama with 60% of them commenting that it is good. While the result does not show satisfaction among all the users, it is important to note that none of them had commented negatively about it; however, there was a significant portion of the respondents reporting a neutral satisfaction. Our findings show that Huggy Pajama generally evoked positive emotional responses in the users.

The children users responded that being hugged gave them positive feelings such as love, comfort, happiness, and fun. All users felt that being hugged with Huggy Pajama is comforting and made them happy. A significant 80% responded positively to feeling loved because of the mediated hug. Similarly, 80% reported that the experience of using the system was fun.

80% of the parents found satisfaction through hugging using Huggy Pajama. Their reported favorite responses from their children were those in which the children reacted positively to their touch with visual responses, for example, smiling and casting joyful glances.

The reaction to the first hug was mixed, with participants reporting feelings such as "surprise" and feeling "a little weird". However, when children were asked to recall their favorite hug received in the experiment, it was reported to be when parents are "not instructed to do so", and when "the scenario thing felt really real". None of the respondents reported any discomfort from the system, and all participants related their enjoyment to the feeling of being immersed in the activity. This may be due to some sense of the technology becoming transparent to the users, however, the survey also identified that the realism for the touch sensation is still lacking. Many felt that the current prototype acts like a pressure device and does not fully reproduce the fidelity of human touch.

From the pre-test questionnaire, we observed that most of the participants do not have the habit of hugging their parents. Our system has the potential to change such aspects of social norm, by providing a means of expressing themselves better. For example, in the case of a father and daughter pair, both parent and child do not practice hugging one another in their daily life. However, during the study, they were the only users who voiced their preference for a Huggy Pajama hug over a physical hug. For them, the mediated hug, though not real, is better than no hug at all even in real life.

However, this positive outcome must be countered by recognition of the negative experiences that users also encountered. In the case of the child participants, all have unanimously agreed that there was no disruption experienced during their activity. On the other hand, for the parents, when asked if they encountered any disruption during the activity, two users expressed that they did expect some sort of feedback. Such feedback with regards to its action with the control itself and feedback of the receiver includes "how well the hug is felt by the child?"

One participant reportedly hugs her mother regularly. However, when taking part in this study, she finds the hug received for the first time "a little weird honestly" but was able to find comfort in it as the conversation carried on. Nevertheless, this user's evaluation of the potential for the Huggy Pajama to support her activities of communicating with her loved one was overwhelmingly positive. For her, the realism in the Huggy Pajama (as if her parent was giving her a hug in real time) was a key benefit:

"When she (participant's mother) said she misses me and that this scenario thing felt really real. She feels emotional. I felt that the hug really came from her and not just from a device."

As with any new communication medium, the understandability through an easily transferable conceptual model from designer to user is important. The initial view of the Huggy Pajama system was reported by some respondents as complex and intimidating initially, however, the all reported that they quickly grasped the proper usage. The respondents reported that the formal qualities of Huggy Pajama provided a good conceptual model mapped to its operation; most participants (90%) managed to use Huggy Pajama without referring back to the moderators after the initial brief demonstration. None of the participants reported encountering any difficulties in using the system.

7.5 Conclusion

Huggy Pajama is a novel wearable system that promotes physical interaction in remote communication between parents and children by enabling each to hug one another through a hugging interface device and a wearable, hug reproducing jacket connected through the Internet. One major contribution is the design of a remote communication system with the ability to sense and reproduce touch and hugs between two people. An additional mode of communication is provided by the incorporated cute and expressive interfaces for the conveyance of emotions between parent and children.

We believe that computer mediated touch is an important form of human communication and will allow for major improvement in achieving meaningful remote presence. To further this goal, in this chapter we described a fundamental study examining human brain activity when using computer mediated touch devices compared with real physical touch. The results of the study described are significant because they help to provide evidence supporting the goal of creating computer mediated touch which can produce a similar affective response from humans relative to a real physical touch. In addition, user feedback was gathered giving an indication of user preferences, usability, and aesthetic choices, which will be used guide further design iterations of the system. Using these results, further developments in remote touch systems can be invented providing great benefits in remote mediated human communication.

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Chapter 8
Culture Computing: Interactive Technology to Explore Culture

8.1 Introduction

Culture, after it began to appear in the English language during the late eighteenth century, was regarded as the intellectual and spiritual cultivation of an individual or a social group. The word culture, which was derived from the Latin word *cultural* meaning *to cultivate*, has sparked controversies over its definitions. Raymond Williams [34] in his dealing with the definition of culture recognized three general categories. The first being the "ideal" in which culture is the state or the process of human perfection. The second is the "documentary" which refers to the body of intellectual and imaginative work being deemed as culture. The third is the "social" in which culture is a description of a certain way of life which expresses its meanings and values in art, learning, intuitions and behavioral patterns. Clifford Geertz [5] recognizes culture as essentially a semiotic one. He described man as an animal suspended in a web of significance, which Geertz understand as the culture and studying it is an interpretative one in search of meanings. Social anthropologist Ulf Hannerz [7] believes that culture is collective and above all a matter of meanings. He further adds that culture is the meanings which people create and which creates people as members of society.

In the rapidly transforming landscape of modern world, communicating traditional cultural aspects has to be cultivated within the same environment utilizing the existing channels thus influencing the participation. The integration of "cultural layer" and "computer layer" introduces intense challenges [15]. Culture computing is a new kind of computing system that introduces and transforms cultures through computer supported activities. Cultural computing uses scientific methods to model traditional cultures so that users could interact and experience these cultures through modern computing applications. As creativity is the mutual foundation of culture, science and technology, cultural computing explores and develops technology to advance creative activities that would be a positive impact on contemporary lifestyles and culture.

In this chapter, we present an overview of cultural computing research and the main features of cultural computing systems. We then present three cultural computing prototype systems developed in our research laboratory, namely Media Me,

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BlogWall and Confucius Computer. User evaluation results are also presented and discussed.

8.2 Prior Research

There have been numerous efforts done in Cultural Computing over the past few years to reinstate traditional cultures using new dimensions or mediums to explore culture. Researchers were arguing throughout the years on how to utilize computing technologies to explore the human experience or to explore the world. The purpose behind these new computing tools is not only to fill the gap between human and their societies but also to explore and experience other cultures, too.

Some of the cultural computing projects help users understand the underlying cultural values, for example, Zenetic Computer [30], while some prompt the users to question them, for example, Alice [9]. Zenetic Computer uses computing as a method for cultural translation. It offers users a chance to engage and understand Buddhist principles of "re-creation" of the self. On the other hand, Alice is an augmented reality narrative with intelligent agents acting as characters who lead the user through virtual and real locations, moral choices and emotional states.

Another example is Hitch Haiku [31], in which the authors studied the reproduction of traditional haiku, a Japanese minimal poem form, by a computer. A user chooses arbitrary phrases from a chapter of a famous Japanese essay called "1000 Books and 1000 Nights", and the system generates a haiku which includes the essence, then translates it into English. Therefore, the essence of a Japanese book can reach those unfamiliar with traditional poetry.

On the other hand, Virtual Reality (VR) technology is also explored in the digital heritage domain. VR technology provides an important educational tool to recreate the cultural heritage content in an immersive high-quality 3D environment for the users to enter and experience the culture in real time [29]. In the project "Interacting with the virtually recreated Peranakans" [28], the goal was to digitally recreate the Peranakans'[1] cultural heritage incorporating intuitive interaction techniques using VR technology. A 3D avatar of an Asian Virtual Tour Guide has been built in an immersive 3D environment to guide the visitors through the environment and interaction with a real Chinese calligraphy brush is provided.

We are inspired by the encouraging results from the above cultural computing projects. We would like to extend the cultural computing research into new global cultural domains like Sri Lankan and Chinese cultures, and also poetry literature. We employ extensive modern digital interfacing technologies, for example, SMS, social network chat, public social display and real time video mosaic. We enable the users to explore traditional cultures and literature through the use of modern everyday computing applications.

[1]Peranakans are the descendants of the very early immigrants to the Nusantara region, including both the British Straits Settlements of Malaya and the Dutch-controlled island of Java.

8.3 Features of Cultural Computing

Based on existing works in cultural computing, there are several common features in current Cultural Computing systems. The our main features are summarized below:

Visual Technology Culture is a collective practice of a community or a society through which meaning communicated visual, aural or textual representations. Visual cultural practices provide a physical and psychical place for individual participants to inhabit and cultivate [27]. Thus visual is the stage where meanings are created and contested. Most of the cultural computing systems provide visual experience by using different kinds of visual technology. The aim of the visual technology is to impart information, meaning and pleasure to the consumer through numerous visual events using an interface [22].

Social Interaction Interaction with the society is one of the key factors of human beings in their day-to-day life and a part of most of the cultures. At every moment, humans are interacting with society in different ways. However, from the last few decades people and/or the societies are seriously obsessed with digital age media. As a result of this phenomenon, their social interactions seem to be diminishing, and exploring the cultural values becomes less important than before [11]. Cultural computing is introduced to conquer this divide between the culture and the people in the existing digital era. Hence people are encouraged to interact not only with their own cultures but also with others.

Bit Literature Cultural computing systems also aim to provide users with dynamic ways of experiencing and exploring cultures. Static literature found in traditional passive media, for example, books, only provides a linear understanding of complex multidimensional cultures, which may not provide comprehensive perspectives toward understanding of cultures, thus restricting the learning process. Bit literature is a new form of computer generated literature based on algorithmic composition of literature generated from both digital bits and literature bits. Bits of users' input and bits of literature (small chunks of literature) from the knowledge database interplay with the computer algorithm to generate digital bits literature. Bit literature is very relevant in the digital age because people's interaction and understanding of literature is changing. We are in the age of instant messaging, short message system (SMS), Twitter, etc. and bits of literature may be better fitted in such communication channels. Users from our modern society could significantly benefit from a more interactive and personalized literature, which is not possible in passive media.

Cross-cultural Making different cultures accessible to people is another main feature of cultural computing systems. Language barrier, which happens in communication without common language, keeps people away from accessing original cultures. For example, it is difficult for western people to study original Confucius classics written in the old Chinese language. The rapidly-changing communication medium, from paper-based to electronic-based, also causes the difficulties for young people to access traditional cultures. Younger generation gets absorbed into the popular cultures, such as the Internet and they are less interested in reading books. Literary arts such as poetry are less interesting to them [16]. Many of them would not go through the literary work such as poetry just for the joy of it [1]. Therefore, cultural computing aims to translate different cultures into a new and common "language" and "communication medium", so that people, especially younger generation, could experience different cultures easily.

In order to address the barrier in cross-cultural communication and to promote the socio-cultural interaction, by using the concept of visual technology and bit literature, we have created three cultural computing systems, Media Me, BlogWall and Confucius Computers. The cultural computing features of our projects are summarized in Table 8.1, and the following sections will describe them in detail.

8.4 Media Me

8.4.1 Introduction

Media Me is a new form of personal media where a person can create and broadcast his/her own customized contents as image elements. For the current version of Media Me, religious, cultural, and historical movies of Sri Lanka are used to create a meaningful video mosaic. This system can also be used for educational purposes in an interactive way, for example, for exploring the national heritage of Sri Lanka. Similarly, the system also can be easily extended to explore various other cultures.

As an artistic reflection on new personal media, Media Me is an interactive video installation that displays a captured image of a person as a video mosaic [13, 14] made of hundreds of videos. We literally turn the body into videos, which artistically represent the revolution in personal media. Videos are continuously arranged in real time to form a mosaic representation of the background and to provide meaningful contents, such as cultural and historical media. When no image is captured by the system, Media Me activates and reflects the media itself by creating a mosaic of cultural and historical content.

Table 8.1 Cultural computing features of Media Me, BlogWall and Confucius Computer

Feature	Details	
Visual Technology	Media Me	Research communicates comprehensive information on Sri Lankan cultural heritage. Users interacting with the system obtain a visual experience with the dynamic contents on the screen with their color, use of light, and exposure. The experience observed from the system could motivate users to explore the Sri Lankan culture and heritage more
	Blogwall	It creates novel poetries using poetry mixing up technology to deliver a creative and pleasant feeling to the user with calm and attractive visuals which encourage people to explore the system functions. The next major step of this research is to visualize the poetry mixing up process in a more aesthetic way
	Confucius Computer	It visualizes virtual Confucius thinking process to give users an insight to the complex flow of thoughts. It also uses beautiful dynamic Chinese paintings to allow users learn about traditional ancient cycles of balance and positive music based on Confucius philosophy
Social Interaction	Media Me	It is a media interactive art work which comments on the bidirectional relationship between people and the media through the use of a real-time video mosaic. It also provides the means to educate the masses including children while entertaining them. This will also bring new ways of communication between people and media, and new forms of social, educational, and cultural interaction
	Blogwall	It uses short message service as the medium of enabling interactions with large public displays using mobile phone. It can create technologically supported public discourse spheres in which they can both represent personal views and practice new ways of forming collective opinions and shared poetry. By using a mobile phone, even a novice user can now become a poet by interacting with the system
	Confucius Computer	It is designed for grandparents and parents to play simultaneously with children in order to promote intergenerational interaction. It provides a good avenue for grandparents to share their knowledge and values to the younger ones through interesting computing applications. At the same time, the grandparents can learn from the children about the usage of new media and technology

Table 8.1 (continued)

Feature	Details	
Bit Literature	Media Me	The dynamic and personalized content created by Media Me illustrates Sri Lankan cultural heritage literature in a dynamic and more interesting way to explore. Dynamic arranging of content will motivate the user to explore and interact with other cultures rather than referring to the static literature. Alternatively, the users could use personal videos to experience the cultures in an interesting manner. For example, a personal video could play in foreground, while videos with cultural heritage are playing in the background
	Blogwall	It generates a novel bit literature, poetry mix-up, by mixing several existing poems, which provides a surprising and unpredictable experience. The system analyzes the emotional weight of the input short message and generates a poetry mix-up based on this emotional context. The final poem generated by the system is a novel and dynamic poem which is based on the user's SMS text
	Confucius Computer	It provides an interactive and personalized advice to the users based on their input. The system merges cultural values and philosophies into user's context, hence sparking the user's initiative of learning something new. The user can experience deep cultural philosophy through small bits of literary replies and chats
Cross-cultural Accessibility	Media Me	Even though Media Me system currently consists of Sri Lankan cultural videos only, it is capable of using any cultural content that could be fed into the system to explore other cultures. The users even not fluent in Sri Lankan language, Sinhala, can get to know the culture better and be motivated for further explorations
	Blogwall	It uses poems from old generations during the mix-up process inside the system. It brings up old and traditional cultural content and style into the new digital world of youth. Alternatively, the system is capable enough to allow for other cultural experiences by changing the poem database with applicable cultural content
	Confucius Computer	It uses modern media like Facebook and MSN to allow users have a deep cultural interaction with virtual Confucius. Users are also able to interact with virtual Confucius using English and graphical interfaces without the need to understand the complex traditional Chinese text

8.4.2 Motivation

Sri Lanka has a grand culture influenced strongly by the teachings of Lord Buddha and Buddhist rituals. It is not only Buddhism which radically changed the Sri Lankan society but the appearance of Indian industries of arts and crafts and the Brahmi alphabet [21]. These new influxes had affected the agricultural community of pre-Buddhist era, shaping them into a nation with a multifaceted culture. Buddhism has been established as the state religion and the relationship that had developed between the religion and state is well defined and amicably accepted, and each drawing strength from the association [2]. Thus began the long esthetic journey in the form of religious art and literature where the religious institution initiated and the state sponsored. Great Monastic establishments of ancient Sri Lanka such as Mahavihara, Abhayagiriya and Jetawana established their own form of fine art, which featured distinctively unique characteristics that instigated the grand cultural prototype in Sri Lanka.

The Buddhism and later the integration of Hindu rituals have enriched the culture of Sri Lanka, making it very significant in every aspect. Modern generation affected by the fast moving global finances and global concepts, with their tendencies towards global cultural trends falling away from the traditional cultural roots that have developed over many millennia. Modern generation has changed their attitude towards grand narrations in history, thus endangering the tangible and intangible cultural roots which belong to the future generations. The main intension of this research is to encourage people of modern generation to participate in the tour of experience in traditional cultural aspects without separating them or forcing them away from their familiar interactive digital environment.

One of the main advantages of using these computing techniques to explore Buddhism is that users can personalize the system according to their interest. Television has been the mass media for broadcasting media content for a long time. However, the developments in broadband Internet and social networks have made it possible for individuals to use their own personal media as broadcast media. As an example, users can capture and load their own recorded interesting cultural videos into the system. As younger generations are more willing to engage in novel concepts, this system can be more popular among people of the new generation. The simplicity and the user friendliness of the system promote its users to take advantage of the system generally.

8.4.3 System Description

The main component of the system is the pre-stored videos, which reside on the computer, categorized by selected topics in a central repository. The camera attached to the system captures real time image sequences, and then each image is built using pre-stored video sequences. The system analyzes each area of the foreground and

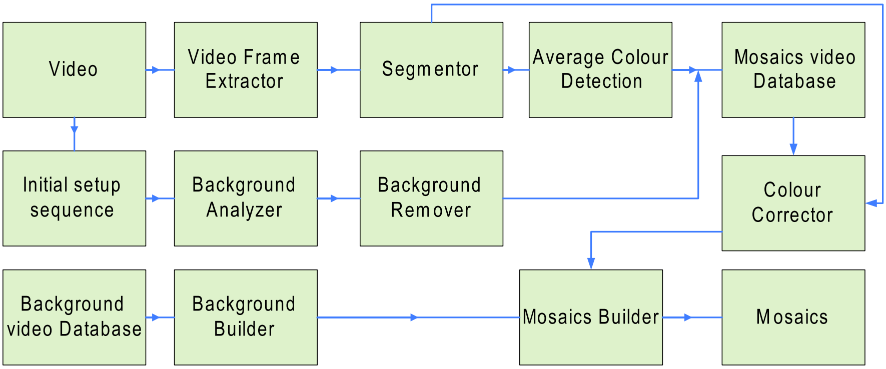

Fig. 8.1 Media Me system architecture

selects a video clip that can substitute that area. Some level of color correction is applied to the foreground video clips to attain a more natural look and feel.

When the system is initialized, the average color in the background is replaced by the system with extracted video frames from pre-stored videos that illuminate historical and cultural heritage of Sri Lanka. The full system architecture is shown in Fig. 8.1.

The main system components are a video camera, a computer, a green background screen and an electronic projector. The average color of the background is computed during the system initialization process and it is used to remove the background from the extracted video frame. The camera captures the image of the person who stands in front of the blue screen. The foreground is segmented to rectangular areas and the average color of each of them is calculated. This average color is used to find matching video clips from the video repository. Then the system outputs the final images with modified foreground and background images as in Fig. 8.2.

The capturing process uses Open Computer Vision (OpenCV) libraries to capture video frames (image sequences) from the video camera. When OpenCV acquires an image frame from the video stream, it passes a pointer to an "image structure" defined in a callback function in the application. However, the system may not be able to process the images at the same rate as OpenCV is acquiring them. Therefore, a Boolean variable is set to indicate that the system is ready to accept the image. If the system is ready to accept, it will clone the original image received into the callback function. When the system finishes processing the current image, it sets the Boolean variable, indicating that it is ready to accept a new image.

The video clips in the repository are pre-analyzed and organized based on their average color. Since the system has only a finite number of videos, small color correction is applied to the selected video clips in order to attain the realistic look and feel. The video clips used for the foreground in the repository have size of 40×30 pixels and are pre-analyzed and organized based on their average color. The average color is used to calculate an index that is used to find a matching video clips from the video repository. The background of the original video is replaced

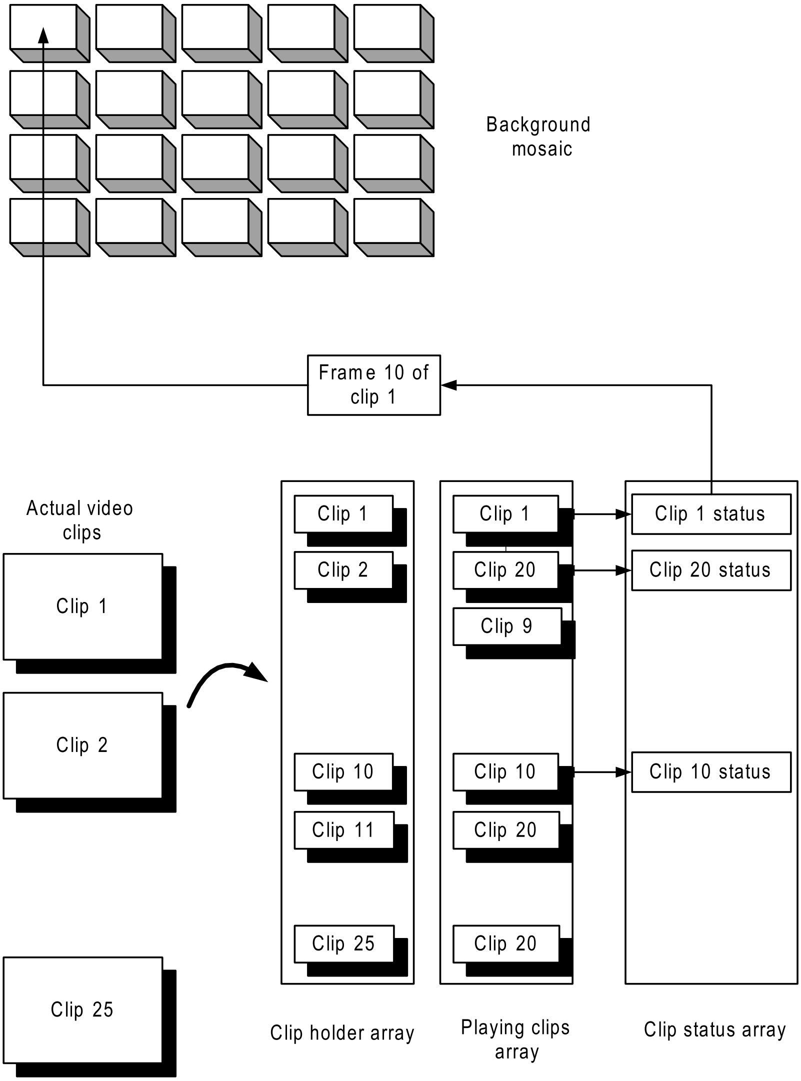

Fig. 8.2 Clip selection

by larger mosaic videos. The average and standard deviation of the background is calculated and used to identify the background of the video.

Finally, the background and the foreground are combined to create the final mosaic as in Fig. 8.3. The process of combining the background and foreground videos applies small color correction to the pixels of the foreground clips to attain a realistic look and feel. The electronic projector projects the final video mosaic onto a large screen in front of the person.

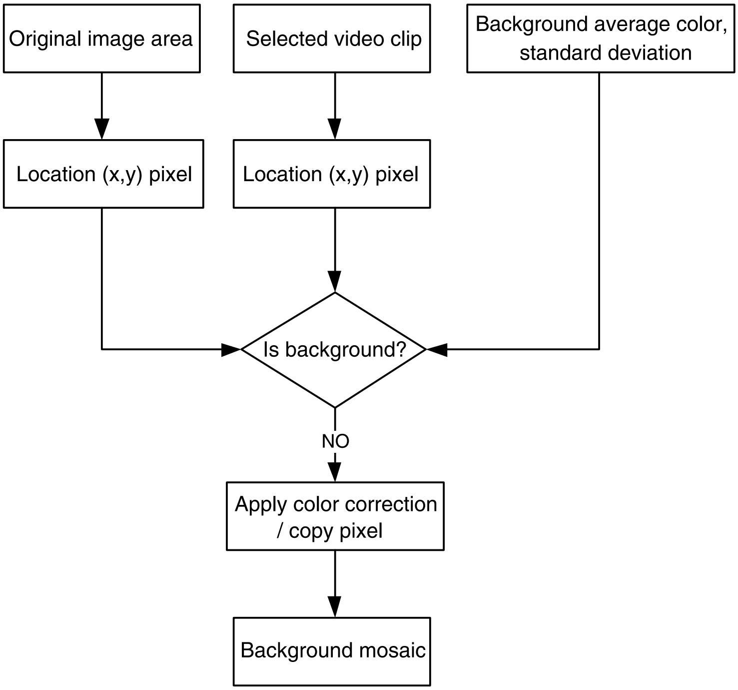

Fig. 8.3 Final video mosaic

The index used to find matching video clips from the video repository is computed as

$$Index = floor(B/32) \times 64 + floor(G/32) \times 8 + floor(R/32), \qquad (8.1)$$

where $floor(x)$ is the function that returns the largest integral value that is not greater than x, and

- B = blue value of the average color of the region,
- G = green value of the average color of the region,
- R = red value of the average color of the region.

8.4.4 Video Indexing

Based on the indexing, the system required a total of 512 ($8 \times 8 \times 8$) videos. However, a normal computer cannot handle such a large number of videos. Therefore, an intermediate array was used to expand a smaller number of videos. In reality, the system consists of 216 video clips. Those videos are duplicated to a color space of 512. One array of size 216 is holding the reference to the video clips, and the expansion array is holding the index to that array. Multiple elements in the expansion

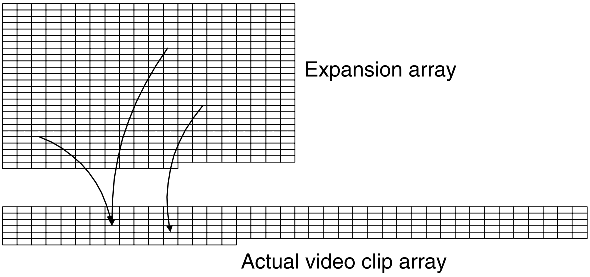

Fig. 8.4 Video indexing

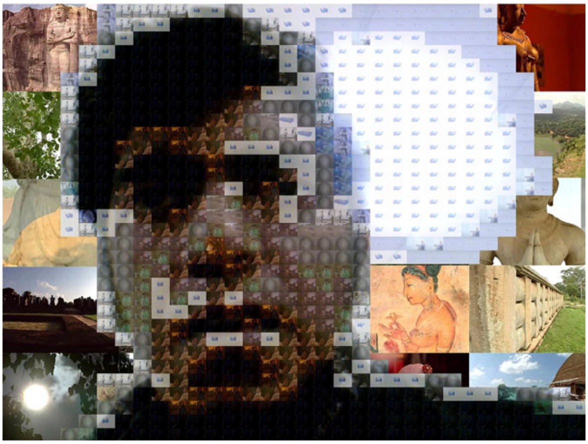

Fig. 8.5 National heritage of Sri Lanka

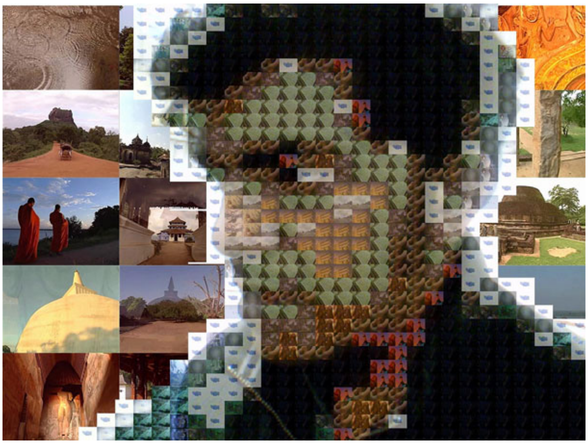

Fig. 8.6 Buddhism in Sri Lanka

array are referring to the same element (video) in the video array as illustrated in Fig. 8.4.

In Fig. 8.5, the face (foreground) and the background mosaic are constructed with video clips showing national heritage of Sri Lanka. Similarly, Fig. 8.6 shows the mosaic constructed from videos of Buddhism in Sri Lanka. The background videos

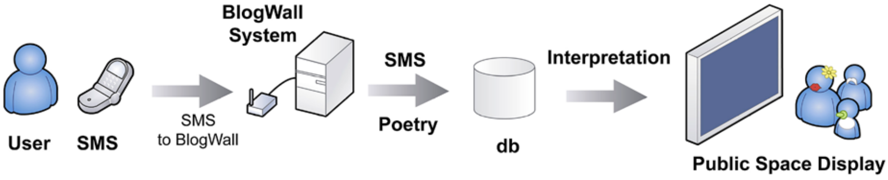

Fig. 8.7 Concept design of BlogWall

are randomly selected and arranged by the system. The system analyzes each area of the foreground and selects a video clip that can substitute that area. As shown in the figure, some level of color correction is applied to the foreground video clips to attain a more natural look and feel.

8.5 BlogWall

8.5.1 Introduction

BlogWall is an extension of the existing text messaging to a new level of self-expression and public communication, combining visual art and poetry. It provides a new form of communication in the networked digital era which represents a combination of digital bits and cultural bits. Mixing poetry is the major element of this system which transforms the users into experiencing the state of being a poet by mixing short messages into poems.

As seen in Fig. 8.7, the user basically sends a short message to the system which contains a pre-configured mobile number. Then the extracted text from the SMS will be transferred to the processing unit, excluding any inappropriate words, will be processed and mixed to generate new poetry, and the end result will be displayed.

8.5.2 Motivation

Interacting by reciting or writing poetry has been a very energetic practice from the ancient times. Poetry is considered as one of the most highly intellectual forms of communication and an exceedingly refined mode of sharing information. Wordsworth considered poetry as a result of the overflow of uncontrollable feelings [17]. From rulers, courtiers, clergy to civilians, many participated in the interactive exchange of culture through poetry. Roman poets of the Imperial times wrote poetry to interpret and glorify the emperor to the public, thus surprisingly communicating the real person to the masses [20]. Japanese Emperor Tenji (626–672), a genuine poet himself, had a very literary oriented court where a Princess had introduced the famous debate in lyrics on which season is much lovelier, Spring or Autumn; the topic, to this day, is able to evoke a highly interactive dialog [17]. The very famous Japanese literary work "The Tale of Genji" [25] reveals most eloquently the poetic communications of Genji which was exceedingly enterprising form of interaction between the various subjects. Japanese Haiku is also one of the entrancing conversations with the nature and with vernacular injects that transcend the social divisions, thus making it Japan's most influential contribution to the global communication [26].

In the new age of digital communication, instant messaging, short messaging, blogging and similar applications, instead of poetry, are more and more widely used by people from all over the world. People are beginning to express themselves openly and also read in the form of short bits of information, such as SMS and Twitter, which we can term a new form of literature bits. The media mix strategy also disseminates content across broadcast media and portable entertainment technologies, and alternatively, this permits communication based on various forms of social interaction between users [12]. Mixing was made popular in hip-hop culture during the 1980s and 1990s, and has continued to be musical and visual DJ (disk jockey) and VJ (video jockey) culture which young people presently enjoy. Regardless of the context, the essential idea remains the same. A mash-up allows users to combine information of varying granularity from different possibly disparate sources [18]. Consequently, a new type of communication system is in need to facilitate the interactive culture of digital communication, literature bits, and mash-up.

From both literature-bits (short bits of writing) and digital-bits (electric communication) we can invent "bit literature" and introduce digital poetry as a new form of communication. Therefore, by blending SMS and poetry, we have developed a poetry mixer called BlogWall to extend SMS (Short Message Service) to a new level of self expression and social communication. This research is an exploration in search of new avenues of communication opened to embrace the traditional poetry while providing the experience of the contemporaneity. One of the main advantages of this system is that it can cross all cultures and build upon the constant short message communication which people are expressing themselves in our connected society.

8.5.3 System Description

The general setup of BlogWall requires a high-end computer with a good graphics card, a projector, and a screen. Dedicated GSM/GPRS modem is used to receive SMS messages. The user stands in front of the projector screen and sends an SMS to a given number. The application issues AT commands to the modem to locate the SMS. All the messages received by the server will be written to a log file along with originator phone number and the date/time. The application consists of several modes of operation. Based on the enabled modes, it offers different services to the user. The complete system architecture is shown in Fig. 8.8.

Even though the main focus of BlogWall is poetry, there are several other ways it can be used. The additional modes of BlogWall can be activated based on user's requirements. These modes are mainly used as value addition to the overall system.

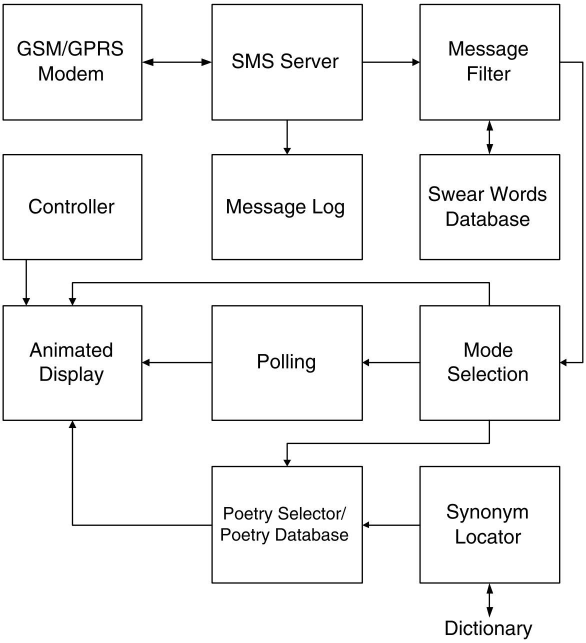

Fig. 8.8 System architecture

8.5.3.1 Standard Display Mode

If the application is in the standard display mode, it will immediately display the text message with some animation. When the system receives an SMS, it selects a random animation for the SMS.

8.5.3.2 Polling Mode

The polling function is used to collect user opinions. The system displays a polling question and available answers as shown in Fig. 8.9. The answers are indexed by a single alphabetical letter within parentheses. To vote, users send SMSs with appropriate indexed letter of the answer to the system. BlogWall also has the capability to provide statistical data to system administrators.

8.5.3.3 Keyword Triggering Mode

Keyword triggering mode enables the application to trigger an internal function based on a word in the SMS. This feature is somewhat similar to the features found in popular chat programs like Windows Messenger. For example, if the SMS contains word "love" the application may replace the word "love" with an image of

Fig. 8.9 Polling mode of BlogWall

a heart. The keyword triggering mode can also display a small verse based on the words found in the SMS. The images as well as verses are selected from an internal database.

8.5.3.4 Poetry Mixing Mode

The most prominent feature of the application is its ability to mix poetry. In the poetry mode of BlogWall, a poem will be created with the means of the user SMS. The application enables the user to assume the role of a poetry jockey. The main system component, the poetry generator consists of several building blocks as shown in Fig. 8.10. By integrating several intelligent methods such as NLP (Natural Language processing) and Information retrieval techniques, the system is capable enough to generate poems which have both meaningful and emotional weights to entertain the users. The system details will now be outlined.

When the short message is received by the system, the words in the message are arranged according to their importance by the system. For instance, from the text "I love thunder and rain", the words "love", "thunder", "rain" would be the most uncommon and important words to select. Common words such as "I" and, "the" would not be helpful in identifying a suitable poetry line. The uncommon words such as "thunder" can be more valuable in identifying a suitable poetry line. The system is also able to obtain synonyms from the dictionary [4] to expand the search criteria. This might enable the system to provide exciting and surprising results at the end.

The importance of a particular word is denoted by a numerical weight which is often used in information retrieval and text mining. This number, called the *tf–idf* weight, is the product of two values: the term frequency *tf* and the inverse document frequency *idf*. The term frequency is a measure of how often a term is found in a collection of documents, in this case poem lines. The inverse document frequency *idf* is used to measure how rare a particular term appears in a given text:

$$w_{i,d} = tf_{i,d} \times \log(n/df_i), \tag{8.2}$$

where $tf_{i,d}$ is term frequency of the ith word in each poem line in a set of d poem lines; n is the total number of poem lines; df_i is the document frequency of the

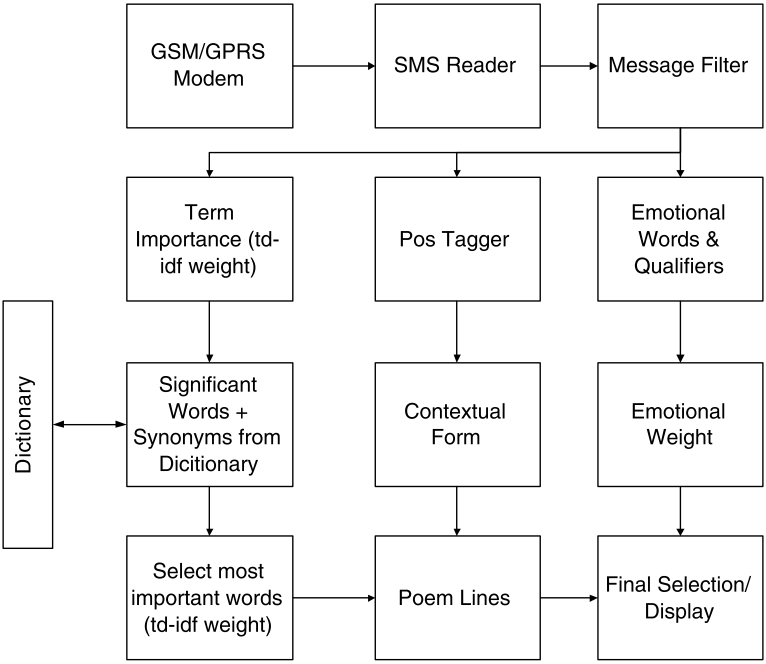

Fig. 8.10 Poetry generation processing of BlogWall

ith word. For each word i, the system then returns poem lines such that $\sum w_{i,d}$ is maximized.

In order to make meaningful connections between the user input and the poem lines in the database, resulting in an original and meaningful poem, word sense disambiguation is necessary and this is the second part of the analysis. The system uses a part of speech (POS) tagger for basic disambiguation. The tagger used in BlogWall is the English POS tagger [32], primarily for the tagging speed and ease of integration. The input message and each poem line in the database are tagged using a POS tagger. In order to avoid poems that do not make sense, these tags are used to pick only those poem lines which use a particular keyword or its synonym in the same sense as in the input message.

The third analysis is the calculation of an emotional weight. Analogous to the *tf–idf* weight described earlier, which ranks words in the input message according to importance, calculation of an emotional weight also is used in the system to rank words according to the input message, which assigns a numerical value based on the emotional content or the mood of the message. The database includes words that can derive the emotional state of the sentence and the corresponding weight of the word along two axes, the degree of arousal and degree of pleasantness. The weights are modeled after the Russell Dimension for emotions [24]. In addition, a database of qualifiers and their corresponding multipliers is also maintained. The system thus analyzes the input message and attaches a numerical value denoting the

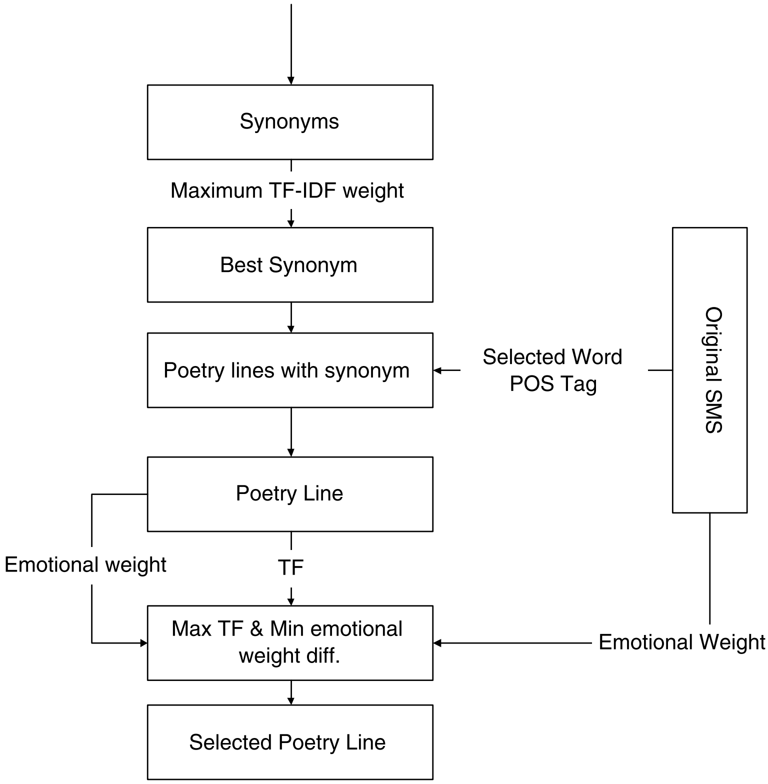

Fig. 8.11 Poetry selection processing of BlogWall

emotional weight. Similarly, all the poem lines in the database will also be assigned a numerical emotional weight. Finally, the system will select the poem lines with the closest weight to the input text.

These three processes are important to the final output. As shown in Fig. 8.11, in the first case, the significant words whose *tf–idf* weights are the highest will be augmented by fetching synonyms from the Internet. A second round of calculation of *tf–idf* weights results in the most important words from this combined set. These words, together with the contextual tag from the POS tagger and the term frequency of the lines, are used to shortlist poem lines. Only the poem lines which contain these words used in the same context (noun, verb, etc.) as well as have the highest term frequency are shortlisted. The final output to the user will be the lines that maximize the term frequency and minimize the emotional weight difference (closest in emotional weight to the input message) of the poetry.

This unique ranking system enables the system to borrow lines of poetry from different poets. Therefore, the final outcome of the system could be unusual, surprising, or maybe amusing.

Table 8.2 POS tagger tags

I	NNS	Used of a single unit or thing
love	NN	Have a great affection or liking for
the	VBP	Definite article
way	VBP	How something is done or how it happens
feel	NNS	Undergo an emotional sensation or be in a particular state of mind
now	DT	In the historical present, at this point in the narration of a series of past events

Table 8.3 Emotional weight of message

x-value (degree of pleasantness)	$+1$
y-value (degree of agitation/arousal)	$+0.6$
On this day, I speak only of the glorious consequence	$(1, 0.6)$

Table 8.4 The *tf–idf* weights of the words

Word	*tf–idf* weight
feel	1.14
way	1.57
now	1.45
love	1.18
I	1.03
the	0.54

8.5.4 An Example of Poetry Mixing

Suppose the user sends the SMS "I love the way I feel now".

For this example, the words are identified by the POS tagger as shown in Table 8.2.

Based on the Russell Dimensions, the line is assigned numerical values based on the emotional weight along two axes. The poetry mixer maintains a list of words and qualifiers that influence the emotional state of the line or message. The system searches for the occurrence of these words in the message. In this example, the result is as shown in Table 8.3. The word "love" produces a positive value $(+1)$ on the degree of pleasantness axis and $+0.6$ on the degree of agitation/arousal.

Important selected words are "feel", "way", and "now" based on term importance. The number of selected words corresponds to the number of poetry lines generated by the system. The application picks three words in the default setting. The *tf–idf* weights of all the words in the SMS are shown in Table 8.4. Note that a weight of -1 indicates that the word or phrase did not appear in the poetry corpus in the mixed poetry.

The system then searches for synonyms for each of these selected words. For example, synonyms found for the word "feel" would include "feeling", "experience", and "sense". Similar sets of synonyms are found for "way" and "now". In this case,

Table 8.5 Fetching synonyms

Word	Synonyms
feel	feeling, flavor, look, smell, spirit, tactile property, tone, experience, find, finger, palpate, sense, feel
way	agency, direction, elbow room, fashion, manner, means, mode, path, room, style, way of life, right smart, way
now	at once, at present, directly, forthwith, immediately, instantly, like a shot, nowadays, right away, straight off, straightaway, today, now

Table 8.6 The *tf–idf* weights of synonyms for "feel"

Word	*tf–idf* weight
sense	1.15
feel	1.14
look	1.02

Table 8.7 The *tf–idf* weights of synonyms for "way"

Word	*tf–idf* weight
style	2.11
path	1.69
room	1.61

Table 8.8 The *tf–idf* weights of synonyms for "now"

Word	*tf–idf* weight
now	1.45
instantly	1.36
forthwith	0.95

the following words were chosen from the set augmented with synonyms: "feel", "way", and "now". The complete sets are shown in Table 8.5.

Based on the types of the original words in the SMS, the system calculates the *tf–idf* weights of all the words in these augmented sets once again. The final lists of *tf–idf* weights, sorted in descending order, are shown in Tables 8.6, 8.7, and 8.8. Note that the words that are not in the system database are not shown in the tables.

In each set, the word with the highest weight is selected ("sense", "style", and "now"). Subsequently in the first step, for each selected word, the system shortlists poetry lines where the term frequency of the word is the highest, the selected word is used in the same context as in the original SMS and the emotional weight of the poetry lines is closest to the emotional weight of the SMS. The results are shown in Tables 8.9, 8.10, and 8.11.

Table 8.9 Poetry lines for "sense" (selected for "feel")

Line	*tf*	Emotional weight
May they also sense the love	0.16	(1, 0.6)
love you now, and sense what may	0.1	(1, 0.6)

Table 8.10 Poetry lines for "style" (selected for "way")

Line	*tf*	Emotional weight
I love so much their style and tone	0.11	(1, 0.6)
I feel I can do my thing without style	0.09	(−0.6, 0)

Table 8.11 Poetry lines for "now" (selected for "now")

Line	*tf*	Emotional weight
And now if I might say	0.16	(0, 0)
I love the way my heart floats now	0.12	(1, 0.6)

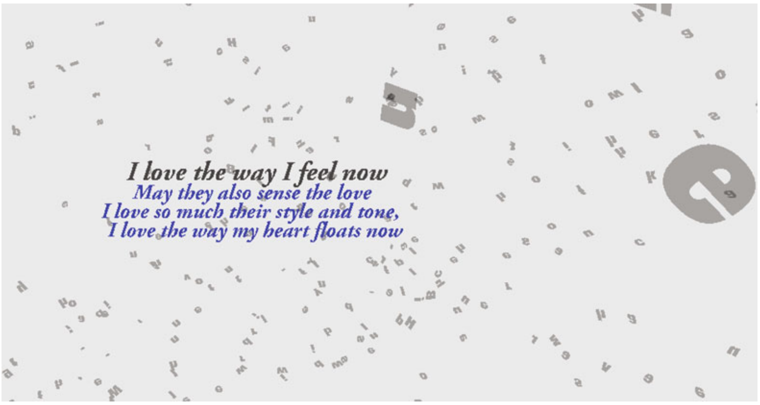

Fig. 8.12 Output of BlogWall poetry mixing. The input SMS is in *black* and the output poetry is in *blue*

In the final phase, the poetry line that maximizes the term frequency and minimizes the emotional weight difference (closest in emotional weight to the input message (which as mentioned above is (1, 0.6))) is selected. The following is the final output of the system as shown in Fig. 8.12.

May they also sense the love
I love so much their style and tone
I love the way my heart floats now

8.6 Confucius Computer

8.6.1 Introduction

Confucius Computer is a new form of illogical cultural computing based on the Eastern paradigms of balance and harmony, which is radically different from the ancient Greek logic normally experienced in computing. It aims to facilitate intergenerational cultural communication by enabling the young to gain deeper understanding of the ancient Chinese culture using the modes of communication they are familiar with. The system uses new media to revive and model these historical philosophies and teachings, presenting them in new contexts, such as online social chat, music and food. The system aims to increase the physical and psychological proximity [33] and understanding between the older and younger generations.

8.6.2 Motivation

Confucianism is an Eastern ethical and philosophical system that has had great impact, especially in the Asian countries, for more than 2500 years. However, Confucian philosophies are extremely complex, and thus may not be easily accessible to people, especially given the cultural, intergenerational, and language barrier. Traditional passive media provides only a linear understanding of his profound teachings, which restricts the learning process. Whereas in our connected digital era, young people are more inclined to use the new literacy of modern Internet based and social digital media. Furthermore, due to global aging population, issues of family intergenerational communication are becoming increasingly relevant [19]. Confucius firmly believed that good family relationships were the key to reforming society:

> The gentleman concerns himself with the root; and if the root is firmly planted, the Way grows.
> (1:2, Analects)

There have been encouraging results on the use of modern communication technology in bridging the intergenerational gap, such as the use of video blogs for the old people to communicate with the young people [6]. Therefore, it motivates us to combine Confucius and eastern philosophies and culture with the media literacy of the new digital generation of social networks, chat and interactive games.

8.6.3 System Description

Confucius Computer is a new form of illogical computing based on the Eastern paradigms of balance and harmony, which are radically different from the ancient Greek logic normally experienced in computing. It aims to facilitate intergenerational cultural communication by enabling young and old to interact and explore ancient Asian cultural heritage. The system uses new media to revive and

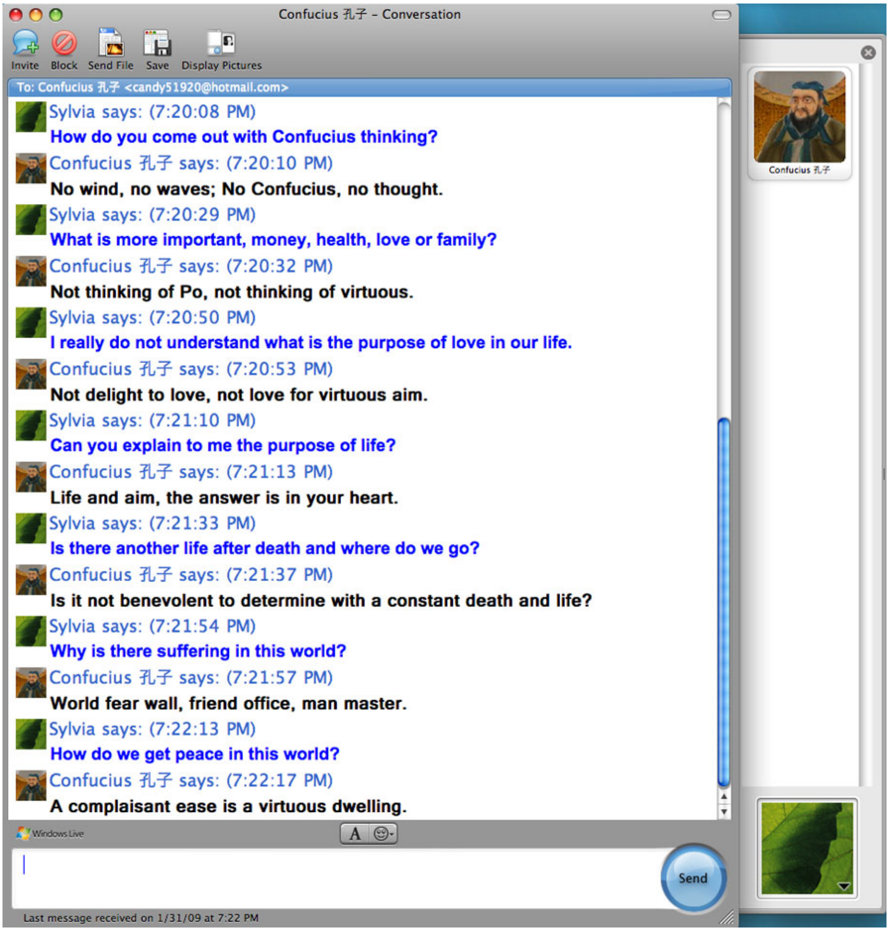

Fig. 8.13 Interactive chat with virtual Confucius

model these historical philosophies and teachings into three sub-systems, Confucius chat, Confucius music-painting and Confucius food, thus enabling people to experience and explore ancient culture using the literacy of digital interactivity.

Confucius chat can be viewed as a new form of computer generated literature, which we call "bit literature", an algorithmic composition of literature generated from both digital-bits and literature-bits. The core of the system is a virtual Confucius thought engine that models Confucius knowledge from the Analects and his teaching method Yin Cai Shi Jiao (teaching student according to his/her aptitude) [8]. Based on the question asked, Virtual Confucius identifies the Yu (sub-domain of knowledge) in the Analects. The system then further queries the user to determine his Hui (aptitude) on that topic. According to Yu and Hui, Virtual Confucius replies to the user. A screenshot of the MSN chat history with virtual Confucius is shown in Fig. 8.13. Users from our modern society could significantly benefit from

Fig. 8.14 Confucius music that filters input music into positive output music

this interactive and personalized advice from ancient virtual Confucius, which is not possible in passive media, such as printed text.

The core virtual model of Confucius also allows customized modules or even widgets. For example, Confucius Computer introduces algorithms to filter and transform any type of music into "positive" music that could promote personal character development [35]. The system filters the timbre, rhythms and scale of the music, and outputs the "positive" music as shown in Fig. 8.14. The output music is in the Chinese pentatonic scale which corresponds to the cosmological theory of the five elements [10]. At the same time, based on the ancient cycles of balance [3] and the five elements, the music is then visualized in the form of a dynamic Chinese painting. Details seen on the painting are generated based on the interaction between musical notes which are expressed as objects whose properties belong to the five elements. For example, the lotus represents the wood element and it corresponds to the second note in the scale. The sequence of notes played generates and destroys objects in the painting based on the cycles of balance, for example, water generates wood. As shown in Fig. 8.15, the fifth note (water) is played after the second note (wood) generates lotus on the water. The painting enables the users to not only visualize Confucius philosophy about music through beautiful Chinese painting, but also to learn about ancient Chinese model of the cycles of balance and the relationship between the five elements.

Another example is the Confucian cooking module as shown in Fig. 8.16. Confucius emphasized that being physically healthy is an act of filial piety. According to

Fig. 8.15 Screenshot of the final Chinese painting generated from Confucius music-painting system

traditional Chinese medicine, the human body is a miniature universe [23]. To maintain a healthy body is to maintain a balance of Yin–Yang. One way to achieve this is by choosing the correct food which is divided into hot, cold and neutral. Factors that influence the choice include the current body state and the external environment (e.g., season). Using deep modeling of such philosophy, the system allows users to gain insights into the complex concept of Yin–Yang in a unique context of food through recipe mixing game.

Before the start of the game, virtual Confucius queries the user's body state by prompting the user to answer some questions typically asked by traditional Chinese physicians as shown in Fig. 8.17. The user then proceeds to mix and match the recipe she desires. The system calculates the Yin and Yang value of the recipe. This value is then compared with the user's personal body state to determine if the recipe is suitable for her. It offers recommendations and alternatives if the recipe is unsuitable.

For example, in Fig. 8.17, the user's body state is balanced but he has chosen mutton, onion and shrimp which are hot food, as the stuffing for the moon-cake. Also he has chosen 1,000 layers moon-cake skin which is warm in nature. Virtual Confucius then commented that the food is too hot for the user and advised him to eat more cold food, for example, bamboo shoots, abalone and red beans.

8.7 Conclusion

In this chapter, we have given an overview of cultural computing research and identified the main features of cultural computing. We have presented three cultural computing systems: Media Me, BlogWall and Confucius Computer. Employing extensive modern interactive media, for example, SMS, social network chat, public

Fig. 8.16 Understanding Yin–Yang concept about food through recipe mixing games

Fig. 8.17 Confucius queries the user's body state by prompting the user to answer some questions

display and interactive video mosaic, and deep modeling of cultures, we have extended cultural computing into new cultural domains, for instance, Sri Lankan, Chinese and poetic cultures. We enable the users to explore traditional cultures and literature through the use of modern everyday computing applications, and have cultural enrichment in an entertaining manner. We are looking into evaluating the learning and transmission of culture using cultural computing systems that we have created. We hope that our research will in the future be used to allow new interactive experiences with all forms of deep traditional culture, including Greek, Arabic, African culture.

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Chapter 9
Kawaii/Cute Interactive Media

9.1 Introduction

The word “cute” is used to describe a number of things, usually related to adorable beauty and innocent attractiveness. The cute aesthetic is something that it not new and has been a component of art since the beginning. The contemporary world is still grappling with the aesthetics of cuteness, and digital interactive systems are just beginning to find the strengths and weaknesses of cuteness. Cuteness in interactive systems is a relatively new development, yet having its roots in the aesthetics of many historical and cultural elements. Symbols of cuteness abound in nature as in the creatures of neotenous proportions; drawing in the care and concern of the parent and the care from a protector. In this chapter, we provide an in depth look at the role of cuteness in interactive systems beginning with a history. Although we aim for a general understanding and examples from different cultures, we particularly focus on the Japanese culture of Kawaii, which has made a large impact around the world, especially in entertainment, fashion, and animation. We then take the approach of defining cuteness in contemporary popular perception. User studies are presented offering an in-depth understanding of key perceptual elements which are identified as cute. The concept of cuteness is analyzed by examining the individual components and by projecting the future of cuteness in a research-oriented design approach. This knowledge provides for the possibility to create a cute filter which can transform inputs and automatically create more cute outputs. The development of the cute social network and entertainment projects are discussed as well, providing an insight into the next generation of interactive systems which bring happiness and comfort to users of all ages and cultures through the soft power of cute.

9.2 The Cute Aesthetic

9.2.1 Kawaii: Cute Culture History and Development in Japan

> The Emptiness (kyomu), the Nothingness (mu) of Japan and of the Orient ... is not the nothingness or emptiness of the West. It is rather the reverse, a universe of Spirit in which

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everything communicates freely with everything, transcending bounds, limitless.
Yasunari Kawabata, 1968 [12]

Japan is a country with a unique culture. Influenced by Chinese high culture from the early days, isolated deliberately from the outside world for centuries, absorption of and adaptation to western cultural elements marked the cultural history of Japan. The overwhelming disappointment in World War II, the nuclear bombing of Hiroshima–Nagasaki, a recent end of the Cold War and subsequent political changes are decisive moments for Japan, which gradually altered its geopolitical attitude towards supremacy. Embracing the western oriented popular cultural ideologies is part of this metamorphosis. Kawaii is a sub-culture of the modern popular culture of Japan. We focus at first on the historical journey of Japanese Kawaii culture that is shaping one of the most technologically affluent nations, its impact on global scale and its modern edition that is contributing to the Japan's universal image as a "soft power." This study in Kawaii is an attempt to decrease the gulf between cultures by understanding the aesthetics of Kawaii, and employing such culture for the increase of comfort and happiness in the design of interactive media systems. To understand the development and importance of Kawaii culture in Japan, let us take a brief look at some relevant history and culture of Japan.

Japan is a small island nation with a long history and a strong sense of cultural identity based on homogeneous people. The first settlements on Japan were recorded during the Palaeolithic period circa 30,000 BC. Primarily a hunter–gatherer culture, the invention of earthenware, and the aesthetic sensibility to beauty of the natural world are the characteristics of the Jomon culture[1] which paved the way for the development of wet-rice farming, iron working, wheel-turned pottery, superior bronze ware and Shinto religious practices. According to Jaroslav Krejčí [16], Shinto bestowed on Japanese a sense of unreserved allegiance, while Confucianism gave all goodness and dignity, and Buddhism contributed the tendency towards submission to inevitability. The arrival of Zen Buddhism which brought simplicity and discipline and already well established Shinto ceremonies influenced the development of distinctive arts of graceful gestures, elaborate rituals, composure and contemplation, gardens, architecture, and the tea ceremony. Haiku poetry and Noh Theater followed by Bunraku and Kabuki marked the classical cultural development.

After almost two and a half centuries of a "closed country" policy by which Japan totally isolated herself from the outside world, the Meiji Restorations arrived, which essentially was a civil war between the Satsuma-Cho-shu Alliance and the Tokugawa Shogunate. Incidentally this period began to ascertain the absolute sovereignty of the emperor. Japan materialized as a world power with colonial inclinations towards Asia. Following World War II, Japan had surfaced to form a new nation, without the constitutional ability to build up an army that could act globally; yet, the same setting has pushed Japan towards the development of another manner with amiable approaches and to became a nation of technological advancements

[1] The first documented culture in the Japanese history. Horticultural and earthenware related ceremonies of Jomon culture are still a part of Japanese Culture.

and drive towards business superiority. Japan started fresh with new, mostly North American cultural models.

The techno-cultural suppleness of nowadays is the result of a difficult and temporary disruption developed out of a very long period of being culturally isolated. Today many cultural transformations in Japan are essentially obsessed with technology [37]. It has also been analyzed that the obsessive relationship that binds Japan with America after World War II initiated people to produce without having a sense of autonomy and to create new popular cultural identities, such as Kawaii [20].

The description of the meaning of Kawaii first appeared during Heian period in 794–1185 AD. A new manner of literature aided by the formation of two forms of simplified Japanese systems of writing in characters based on phonetics was created by the sophisticated aristocratic court society at Heian. Makura no Shoshi (The Pillow Book) written by Sei Shanogon [34], one of the court ladies of the Heian court and an essayist, is a collection expressing the more urbane aspects of the contemporary society. The behavior of the chipping sparrow, the small leaf of a crest and a lazuline jar were among her list of cute objects. Furthermore, the game played at Heian court by aristocrats was named kaiwase, the clam shell game, which involved competing to compose the most refined Waka (31-syllable Japanese poems) while moving 360 clamshells from left to right. Sei Shanogon had applied the word utsulushi to denote the meaning of Kawaii. The old mode of Kawaii, kawayushi first appeared in Konjakumonogatarishu (Tales of times now past), which was the greatest collection of tales of Buddhism in Japan compiled at the end of Heian period. In it the word kawayushi means 'pity.' Vocabvlario da lingoa de Iapam (Vocabulário da Língua do Japão in modern Portuguese), which is a Japanese to Portuguese dictionary published by the Society of Jesuits in Nagasaki, Japan in 1603, contains the word 'Cauaij', and it is considered as the original meaning of Kawaii [31]. From Taisho period till 1945, the word Kawaii was printed in dictionaries as kawayushi, followed by the change of kawayushi to kawayui.

9.2.2 History of Manga

A very related historical effect to understanding Kawaii culture is the development of "Manga" (visual comics arts), as these directly project the Kawaii aesthetic. While being restored to its former glory in 1935, Horyuji temple, the oldest wooden structure in Japan, which was burned down in 670 AD, revealed caricatures of people, animals on the backs of planks on the ceiling of the temple. These caricatures are among the oldest surviving Japanese comic art [11].

Cho-ju–giga, also known as Cho-ju–jinbutsu-giga, is a famous set of four picture scrolls belonging to Ko-zan-ji temple in Kyoto, which incidentally is considered to be the oldest work of Japanese manga. The first two scrolls, illustrating animals (frogs, rabbits and monkeys) frolicking, are assumed to have been drawn in the mid-twelfth century, whereas the third and fourth scrolls date from the thirteenth century. The brush strokes are lively portraying the actions and movements which are central to various episodes.

Instead of hand painted manga, in the Edo period (1603–1867) woodblock techniques for the mass production of illustrated books and prints were developed. In the middle of the Edo period, in 1720, woodblock print publishing method emerged in Osaka. It was considered as the first published manga book that became a commercial success. Uncomplicated lines and exaggerated expressions are essential elements of manga, and the cinematic technique creates an even more expressive medium. To lay the foundation for modern day manga, the artists of long ago imaginatively combined these elements [10].

The earliest usage of modern manga was recorded in 1770s. The growth of the urban middle class during this period resulted in the development of the popular consumption pattern in entertainment where mediums such as manga flourished. Kibyoshi were story books for adults with narrated story placed creatively around the ink brushed illustrations. Most famous were the 1819 AD wood block prints published by Katsushika Hokusai. The turn of the twentieth century marked the arrival of the physical form of modern manga. It was during the Sho-wa period (1926–1989) when manga became a part of everyday life of the Japanese people. Amazingly, the first example of modern day manga was dedicated to the children, the comic strip, "The Adventures of Little Sho" (Sho-Chan no Bo-ken), which is a story about a little boy and a squirrel. Even though Japan provides sufficient evidence to support the historical roots, the ancestors of the modern manga are the European/American-style political cartoons of the latter nineteenth century and the multi-panel comic strips that flourished in American newspapers during the Post War years. In the midst of the defeat, massive destructions and Hiroshima–Nagasaki initiated the new form of modern manga, picture card show and rental manga. Picture card show is a miniature theater with the story drawn on cards which were displayed in theatrical style. And the crowd of young destitute rural youths, who had scaled the cities as migrant workers, were the consumers who created a market for the rental manga.

The 1960s observed the rapid expansion of the story manga relating it to radical political movements and experiments in counter cultural inclinations [14]. Commercial manga advanced and diversified during 1970–1980s, its contents maturing to accommodate the rapidly transforming tastes and attitudes. In 1990s, manga encountered a challenge, the challengers being the computer games, personal computers and the Internet. To Kinsella [13], Modern Japanese manga is a synthesis, a long Japanese tradition of art that entertains. The physical appearance was an invention copied from the West. Manga characters express cartoon tendencies with exaggerated emotional articulations. They convey human emotions in their basic form; swooning to visible excitement, unabashed embarrassment to hopping madness [13]. These are the personal characteristics that are cute, which the generations associate themselves with, developing their individual selves to portray some, if not all, of these cute qualities in varying degree of appropriateness.

The artistic experience of manga gradually developed into cultural production, a collection of imageries with vulnerable qualities which are dreamily adorable, that set out to conquer the popular culture world. The image based culture products at face value seem little more than decorative characters. However, while manga is identified with the masses, these culture products explore the technological landscape of Japan, giving the individual user a means of self expressions and individualization. Kawaii is the sentiment expressed in these aesthetics and culture products.

In the 1970s, Kawaii emerged as a new form of pop culture, which is an integral part of the Japanese culture. Kawaii is a very unconscious obsession. To Takashi Murakami, Kawaii culture is an expression of Japan's post-war impotency and the child-like relationship to the United States [19]. Both the dynamics of manga and Kawaii are inter-related, each enhancing the existence of the other, and both epitomize Japan's susceptibility towards childish tastes and the shelter and safety those tastes offer [23].

9.2.3 Kawaii Culture Development in Modern Japan

During the mid 1970, Japanese teenage females developed a form of handwriting which had become the rage [17]. Written in child-like fashion to communicate with one another, this new childish character style became a phenomenon during the 1970s. A survey conducted in 1985 revealed an estimated crowd of about 5 million were using this new form of writing. The new script was described by a variety of names such as marui ji (round writing), koneko ji (kitten writing), manga ji (comic writing), and burikko ji (fake-child writing) [13].

Romanization of Japanese text could be the birth of cute handwriting. Japanese writing is in vertical strokes, varying in thickness. The new style produced thin even lines, stylized and rounded characters in a blend of English, katakana, and diminutive symbols in cartoon style, like stars, hearts, and adorable faces. The fixation for this style developed to an extreme so that the schools across Japan had to ban using it to discipline school children.

By inventing this new form of handwriting, the younger generation was aspiring to establish themselves as individuals, identifying as a separated entity from the adults and their traditional cultural values. Kawaii, in point of fact, is seen as a rebellion against the traditional cultural values and a belated reaction to the destruction of World War II and its aftermath. Their apparent babyish attitudes conveyed the unexpressed desire to be recognized as a new culture which will not be outmaneuvered or blindly led. They faithfully embrace the cuteness portrayed in Kawaii cultural development. Association of Kawaii with the technological landscape of Japan by customizing and humanizing it [9] gives the Kawaii worshipping generation an inspiration to articulate themselves individually, yet also as a group.

In 1971, a stationary company "Sanrio" established a Kawaii consumer market, developing their strategies targeting the cute crazed teenagers by introducing cute style fancy goods such as cuddly toys, toiletries, pastel in color with frills and ribbons. Hello Kitty [32], a beribboned kitten with an inexpressive face, in pink and white hues with a petite stature is one of the most popular Sanrio cuties. She is now an adored trend enhancing the consumer appeal of products and services of over 22,000 worldwide. Since 1983, Hello Kitty acts as the Ambassador of the children of United States for UNICEF. Sanrio had introduced a range of characters for the Kawaii consumer market such as Chococat [32], Little Twin Stars [32] and My Melody [32].

The commercial appearance of the Kawaii cute is that it should be modern and foreign in design, shape and size must encourage cuddling, adorably soft to senses, pastel in color with frills and ribbons. According to Sharon Kinsella [13], the essential anatomy of a cute cartoon character is small, soft, infantile, mammalian, round, without bodily appendages (arms), without bodily orifices (mouths), non-sexual, mute, insecure, helpless or bewildered. A circle with the bottom half having three dots, two for eyes and one as a smiling mouth is how Takashi Murakami describes the Kawaii scale [19]. Kawaii characters are an inspiration in the first place, manipulated by consumer culture to exploit the cute elements, basically the cheerfulness and optimism.

When Takashi Murakami explored the aesthetic capabilities of the pop culture, he introduced his famous theory of superflat visual culture, a theory which emerged from cultural, political and historical perspective regarding the interaction between high art and subculture, Japan and the United States, and between history and the present day [5]. Arthur Lubow [19] writing for the New York Times mentions Murakami's argument that the flattening process liberated the contemporary Japanese from contemplating the contradictions of Japan's image during World War II and the post-war economic and political maneuverings.

"Becoming Kawaii" with infantile behavior and adaptation of frivolous mannerism and superficial attitude towards profundity and values is the aspiration of the most of the young Japanese. Cute fashion and surrounding oneself with all things Kawaii are not adequate for them to elevate themselves to the blissful stage of Kawaii. Living in a fantasy Kawaii world where every available space is filled with cute things, Japanese cute brigades deliberately disregard the harshness of the realistic world and refuse the maturity that comes with time. Sharon Kinsella [13] noticed that in Kawaii culture young people became popular according to their apparent weakness, dependence and inability rather than their strengths and capabilities. According to Anne Allison [1], cute characters provide a sense of security, intimacy, or connection for people who, in this post-industrial age, lead busy, stressful lives often detached from the company of family or friends, thus making cute attachments their "shadow families."

9.2.4 Kawaii Globalization

Joseph Nye Jr. [26] who introduced the term "soft power" to highlight the importance of cultural factors in world politics, identifies Japan as a "one dimensional" economic power marked by a cultural insularity. Present day Japanese culture is software and service economy oriented, and with the globalization of Japanese soft culture, Japan is recreating its national identity. As Kawaii-craze is becoming the cultural vogue across the continent, mesmerizing the younger generation around the globe whose dream is to associate themselves with the values and lifestyle of Japan, it indicates the emergence of a new Japanese identity. As Saya Shiraishi [33] noted, Japan may be developing what Nye calls "co-optative" behavioral power.

Kawaii is, in fact, now a strong consumer culture. Japan is years ahead of many other countries in adopting strategies and modes for customization; especially dominant mode of customization is Kawaii culture [9]. It has spread all over the world as a universal trend with arrays of inspirations and inventions. Even though they are not directly recognized as Kawaii, most countries are producing their own brands of cute subcultures and not just as an alien impostor but as a culture legitimately their own with aspects that can be trailed back to centuries ago.

In India, Kawaii elements in its culture are reflected in its various mythical literary masterpieces such as Ramayana [36], ancient Sanskrit epic, dated from 500–100 BC, where the character of human/monkey (Hanuman) coveys all cute attributes. Today Indian artists are introducing a baby version of the monkey, appropriately named Baby Hanuman as an animated figure. Lately some of the leading artists in Indian cinematic art cultivated an image of cute nature which has taken Indian fans all over the world by a storm.

South Asian countries have their own cute characters and temperaments, though they cannot be described as Kawaii culture, the basic aspects are visible. "Kolam," a folk dance of Sri Lanka the origin of which is in India, where the dancers wear intricately carved masks, is one of the folk dances famous for its comic wit and hilarious made-up stories and cute characters. Though a strong tangible culture has not developed out of this ritualistic theater it is still attached to the Islanders' sense of innocence and mischief.

In the USA, Kawaii elements are found in the highly cultivated animation industry. Mickey Mouse, a mouse created in 1928 that has become an icon for the Walt Disney Company, Warner Brothers' Bugs Bunny, a harebrained rabbit created in 1939, and Alvin and the Chipmunks, the story of a singing trio of chipmunks created in 1958, are not only a major portion of the present day American culture but also a universal fascination. European attachment to cute can be traced to the appearance of Moomin, a hipo look like round and furry character created originally by a Finnish writer, and Miffy, a female rabbit created in 1955.

The modern electronic era beginning from 1980s is witnessing the Kawaii inspired computerized electronic innovations which are dominating the world as a global phenomenon. Larissa Hjorth states that the use of Kawaii features to familiarize new commodities or technologies has been common practice in the material culture of post-war Japan [9]. The world, it seems, is finding similarities with the technological optimism expressed by Japan's popular cultural creations. Within the cyberspace and interactive games enjoyed all over the world, subcultural Kawaii has lost its submissive nature. Instead, in the dramatic world of consumer culture where consumption is speedy and threshold of boredom is a slender line, each Kawaii character battles for supremacy and then survival. What is greeted today with a squeal of "Kawaii" will not received the same rejoinder tomorrow. As a soft power the surviving grace of Kawaii culture is its undeniable universal appeal which has crossed the cultural and political borders.

9.3 Contemporary Perceptions of Kawaii/Cute

Have you ever found yourself smiling when presented with a cute character on a website or in a video game? Maybe you have noticed that the way a virtual character moves displays a personality of youth or excitement or friendly demeanor. These are often carefully selected elements utilized by the designers to draw in the user and establish a micro-relationship and impart positive feelings. We noticed that in the Japanese culture, the cute aesthetic is widely used by many organizations and for many purposes including mascots for the police, warning signs for dangerous areas, pedestrian detours in public places, company mascots, and video game characters, among others.

Upon further examination, using cute to motivate and inform might seem a strange match; however, there may be something that cute can do which deserves more focus and research to understand. We noticed that the Japanese style of Kawaii embodies a special kind of cute design which could be used to inform designers of interactive media how to engage users in a way which reduces fear, and makes dreary information more acceptable and appealing. An analogy could be thought of as the bitter pill with a flavored layer which makes the consumption of the medicine more agreeable. The medicine itself is beneficial to the patient, but the process of swallowing a bitter pill detracts significantly from his or her happiness level. We draw a parallel to the cold, digital, electronic, and unsettling internal components of a system to the bitter pill. The "flavored coating" is the cute user interface which is made more agreeable by establishing a relationship with the user and delivering the content of the system in a more friendly and attractive way.

This manipulated perception is not only a flavored coating that makes content easier to consume, but also brings the user to a desired frame of mind and attitude and then delivers content that might not otherwise be received. We can imagine this being used to improve educational materials by reducing the fear and apprehension to learn new concepts, and therefore improve the speed of learning. Taking this concept further, it is conceivable to take an engineering approach to cute design to carefully customize the interaction based on individual preferences and transform various inputs into more cute outputs that appeal to the user, stimulating the emotions involved in the cute experience. This automatic transformation could lead to design possibilities not seen before, resulting in new sounds, smells, foods, and visual content in interactive systems. This represents a unique approach, not aiming at replacing the designer, but providing tools to the designer in the pre-production phase and then to the end user, enabling new self-customization of products.

9.4 Cuteness in Interactive Systems

Aside from carefully designing toys to have a special appeal, we feel that cute interactive systems can draw in the user in a special way and motivate action in a way that is unique. In this section, we describe the benefits of using cute. For example, the creation of educational games which help the students learn challenging material, cute companions which help people get through painful rehabilitation sessions, enabling interesting ways for people to interact, and increasing the happiness level in general.

9.4.1 Child-Like Innocence and Play

Kawaii and its predecessors have been associated with an innocent and cute attitude. This attitude is not as helpless as it may seem. It can be tied to the child-like way of seeing the world and allowing oneself to wonder in the beauty and the unknown and to approach things with an inquisitive attitude. Mitchell Resnick's concept of "Lifelong Kindergarten" [21] captures this sentiment. In this example, the philosophy is that the learning process should continue throughout life and that people should set aside the constrictive mindset of the adult world and explore in a child-like way. It frees the user to explore and interact more honestly in an environment that is consequence-free. As Brian Sutton-Smith mentioned in a recent article, the child uses play as a way to learn and move forward, and the adult uses play as a way to move sideways [35]. He mentions that play is a way to raise spirits.

9.4.2 Moments of Surprise

One of the most essential components of a designed Kawaii object or experience is the user being surprised or caught off guard. This disruption to the user plants the initial emotion through which the continuing experience is colored. In the case of signage and static jewelry charms, there may only be one surprise revealed to the user and the micro-relationship is built on this alone. While it may be possible, it is unlikely that richly interactive Kawaii systems have only one moment of surprise. In fact, we find that successful interactive systems have more than a few moments of surprise. Some of the systems involve few moments of surprise and accomplish the intended user impact with these special moments of relationship building. Moments of surprise can come from many aspects of the experience. Manipulation of size and proportion draws the user in and activates the nurturing feeling or simply astonishes the user at the novelty of miniaturization. Also from the visual sense, the expressions of a character are conveyed. If a character is displaying an exaggerated emotion such as happiness or harmless stubbornness, the user recognizes the symbols mostly from visual cues as in the notion of affordances [25], which are design clues that a user perceives that help formulate the realm of possibilities of the potential interaction. For example, in the interaction with musicBottles [22], the user is presented with bottles having stoppers that display to the user an affordance that the bottle could be opened. We are pleased when we make a guess based on clues and the end result confirms. When the user manipulates the first bottle top in the musicBottles, the user in a moment may think "ah, this is just as I expected." The user is then surprised when the action also sets in motion other aspects of the interface such as the music and the lights. musicBottles is crafted to unfold these affordances and guide the user in an elegant way. After the first bottle top is removed, the user may replace the bottle top. The music stops. This may instill a sense of wonder and connection with the interface. The user may then choose a different bottle top to remove. The user is delighted with the fact that music and lights are also envoked, but that the music and sound are different and specific to that bottle delights the user more, and the relationship is strengthened with each bottle and the group of bottles as a whole. With more time, the user manipulates various bottle tops and experiences the individual contribution of each and is compelled to be a conductor. This change of role from a passive observer to a conductor of music is not expected, but is a happy experience. The user is continually surprised when various combinations of bottle tops are removed or replaced and by its compounding effect on the music and lights. When the user has taken inventory of the possibility space, he or she is delighted in solving a puzzle [15]. The moments of surprise can unfold quickly, or in a more slow and controlled manner to extend the amount of excitement and happiness. The unfolding of these moments of surprise could be compared to the narrative construct of aporia and epiphany [24] which are used by game designers and authors to present the user with climactic moments at appropriate times to reward the user and to develop a sense of connectedness to the experience. There is also the possibility that the systems can continually unfold new moments of surprise on an ongoing basis.

9.4.3 Relationship with Object's Personality

When the user exclaims "Kawaii!," the user is acknowledging the fact that the experience is unique and special and involves something that is willfully cute. The most widely used tool to develop the relationship with the user is the projection of a personality of an object. In the case of the Hello Kitty symbol, the gesture and expression of the character is of utmost importance. The cartoon cat is in a sense announcing "Here I am!," and the user attaches emotions and develops an internal narrative explaining the emotions and attitude of the cute animal character.

The viewer is pulled into a relationship with the kitten. Its personality and attitude is conveyed in a non-verbal way to the viewer utilizing the small changes in facial expressions and small symbolic accessories and outfits. The personality of the character itself is a strong element in the Kawaii experience; the viewer is asked to perceive the emotions and understand what motivates the character.

9.5 Studying Cuteness

While we recognize that some design companies tightly guard their secrets of cute in order to maintain their market share, we also recognize the benefits of the power of cute and couldn't help but look deeper into the design of cute. At a conference "Designing Interactive Systems" in Cape Town, South Africa in 2008, we conducted a workshop, "Designing Cute Interactive Media," pulling together researchers also interested in uncovering the aspects of the cute aesthetic.

Among the presentations were scientific user studies which focused on understanding the key elements of user perception of cute including analysis of colors, shapes, proportions, textures, and sounds across users from all ages and genders. Some of the findings showed surprising differences in user preference among the ages and genders. We will include the highlights of our results below, and take a closer look at the concept and definition of cute from a design and engineering perspective.

9.5.1 Defining Cuteness

The first portion of the study was conducted via online questionnaire in which the respondents were asked to provide a definition of cuteness in their own words. Using word frequency analysis, we developed a definition of cuteness as follows:

"Cuteness includes the feelings and emotions that are caused by experiencing something that is charming, cheerful, happy, funny, or something that is very sweet, innocent, or pure. It can stimulate a feeling of adoration, sympathy, or stimulating the care response."

In addition to coming up with a definition of cuteness, we also see that responses included the mention of colors, sounds, motion, feelings, among others. We took the most commonly mentioned variables as input to the design of the subsequent portion of the study.

Using an interactive online survey, 72 respondents from 20 countries were polled, including representation from Asia, Europe, North and South America. Some interesting trends emerged which showed some similar preferences amongst the groups, but also some key differences as well.

9.5.2 Color Selection

When respondents were given the freedom to choose colors from 16 hues in the visible spectrum, the respondents selected as shown in Fig. 9.1. This isolation of color values explored the limits of the trend towards bright and primary colors. The preferences focused on the primary and secondary hues of red, blue, purple with fewer respondent choosing green and yellow.

When the respondents were presented with just a few color samples from a limited number of hues, child respondents showed a very similar preference for selecting brighter colors. When presented with hues that presented ranges of colors with less variance of the individual intensities, there was a tendency for selecting the

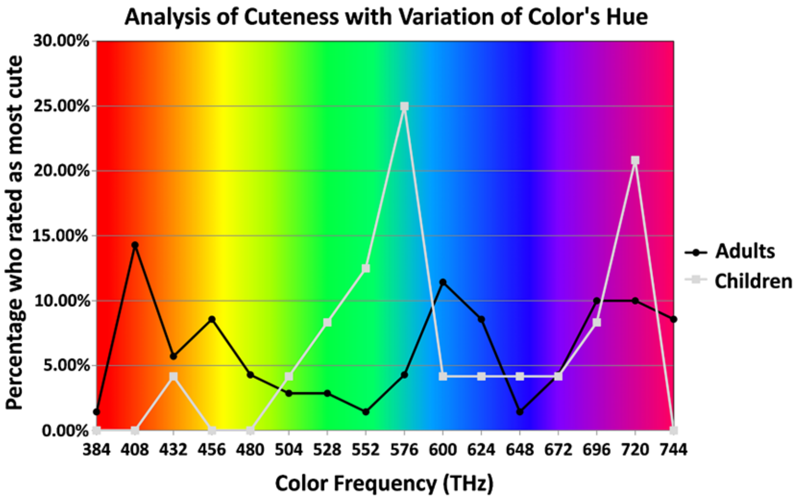

Fig. 9.1 Chart showing the summary of selections of most cute color

colors on the pure ends of the spectrum. In other words, the trend showed stronger preference for primary hues and less preference for grey. Children showed a stronger preference for the greenish blue shade than the older respondents. They also shared a preference for the reddish shades as leading in the selection as shown in Fig. 9.2.

9.5.2.1 Why These Colors?

These trends in the selection for the pure hues and the primary colors could originate in a complex mix between the natural symbols which are instinctual, culturally conditioned symbols, and personal differences in preference and perception. From the natural world, warm colors including red, orange, and yellow, are often seen as a symbol of youth and vitality. The flushed red cheeks of a baby, the bright red of roses and other flowers are examples. It could be that bright pure hue colors convey a sense of willful expression which is not muted with darker shades (mysterious) nor washed out with the paleness of white (less confidence). From a cultural perspective, many cultures especially the Western cultures use the bright primary hues for children and babies as a way to show innocence and purity. Regarding personal preferences, it is not always clear in which cases the selections for cute and colors would deviate from the cultural and instinctual choices, but it could involve other influences from past experiences and/or personal acceptance or rejection of contemporary trends. The influence of color is a complex and well debated issue in the research and philosophy of aesthetics and psychology of perception as mentioned on page 337 of the tome by Arnheim [3].

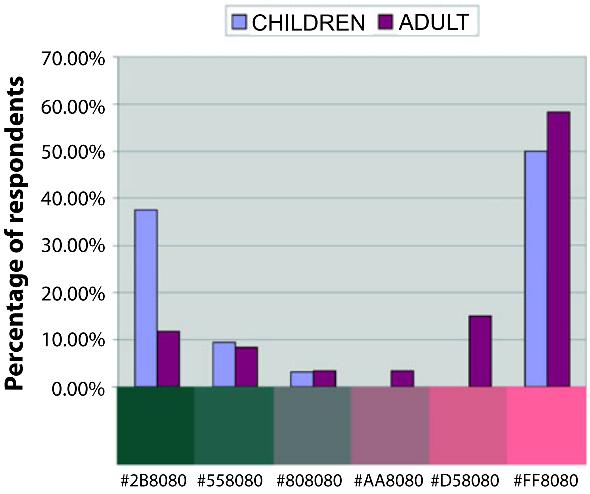

Fig. 9.2 Chart showing the summary of selections of most Kawaii color in the range from a greenish hue to a reddish hue

9.5.3 Texture

The survey for cute ratings and texture was performed by presenting the users with texture samples administered to the respondents such that they could not see the texture, but only make a judgment based on the sensation of placing the hand on the texture sample as instructed by the survey facilitator. There was a noticeable trend in the softness and pile of the textile sample and the cuteness rating. The results showed that as the texture becomes softer and has a longer pile the rating increases. A stronger association with cute was shown only to a certain point beyond which the ratings showed a decline. This showed us that there is a "sweet spot" in the isolated perception of textures and their affect on eliciting Kawaii feelings.

9.5.3.1 Texture Study Details

The user is presented with a texture number, and the test facilitator prepares the texture for the respondent to feel without looking at the color and shape of the sample. The respondent selects the Kawaii rating from the Likert 5 position scale ranging from "Very Cute, Somewhat Cute, Neutral, Somewhat Not Cute," and finally "Not Cute at All." This is repeated until the respondent has experienced all 12 textures. The textures range from very soft to the touch faux fur to rough canvas. The table below shows the types of materials used. The average rating given for each of the textures is shown in Fig. 9.3.

The most highly rated Kawaii texture is shown in Fig. 9.4.

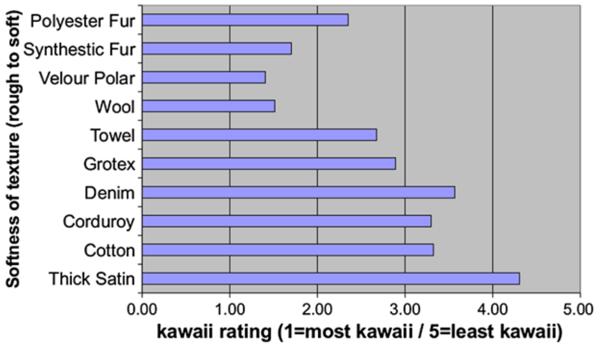

Fig. 9.3 Chart showing that the softness and increase in pile results in a stronger association with Kawaii

Fig. 9.4 Picture depicting the most highly rated Kawaii texture

9.5.3.2 Why These Textures?

These trends in the selection for the longer pile, soft textures is likely related to the examples seen in nature. In the natural world, babies begin their lives as soft and cuddly creatures. The thoughts of kittens or puppies may make a connection with the respondents when they feel the texture samples. It may be this connection to nature which also leads to the lower scores for the unnaturally long pile samples. This feeling of obvious exaggeration and declining scores might provide lessons which show limits to the power of abstraction and manipulation from the real to the surreal.

9.5.4 Motion

Users were presented small animations showing movement of a small black circle on the screen. For each “motion clip,” we instructed users to give a “cute” rating to each of the clips. In addition to the rating, we also allowed for open-ended feedback from the users. The open-ended feedback was helpful in illustrating the rating summaries.

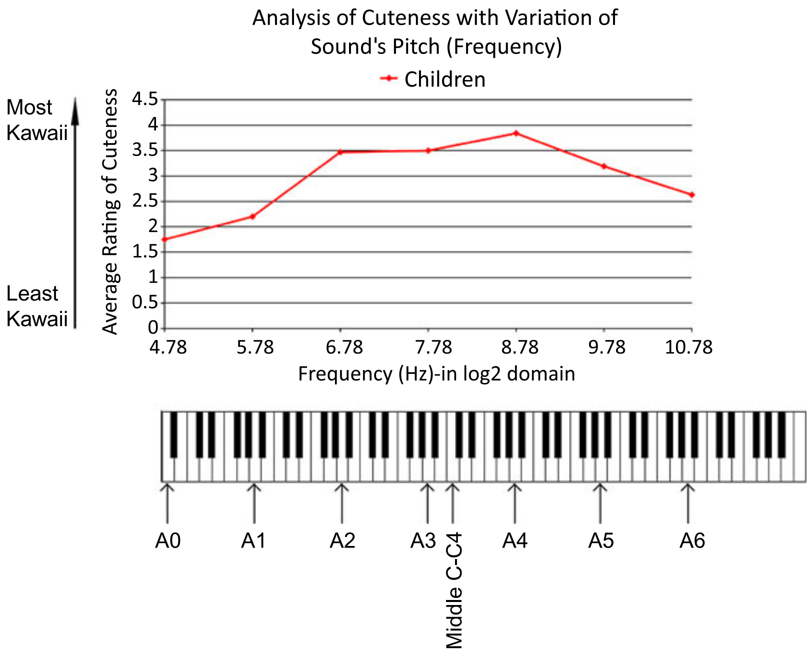

Fig. 9.5 Chart showing that a higher pitch results in a strong association with cuteness

The "motion clip" rated as the most cute depicted the circle moving left to right with small hopping motions. In the open-ended feedback, many responses likened the movement with animal movements and small steps.

9.5.4.1 Why These Movements?

The selection for movements which resemble small hopping motions are likely related to the examples seen in nature such as was provided in the open-ended feedback from the respondents. In nature, the movements of power and aggression are fast and precise, but the movements of the young creatures who are exploring the world and stumbling in awe and wonder covey a more harmless and friendly expression.

9.5.5 Sound

In this test, users were instructed to listen to audio clips and select a "cute" rating for each. We asked the respondent to listen only once and provide their first impression. Each clip presented the same melody, but each clip used a different range of notes. The respondents showed preference for the higher pitch in melody as association with Kawaii as shown in Fig. 9.5.

Additional sound variables such as tempo, rhythm, instrument or voice, sound envelope, echo, and timbre, among others, have shown some interesting results.

9.5.5.1 Why Are These Sounds so Cute?

Again, sounds in nature which convey cuteness are consistent with the results of the perception study. Some examples of high pitched sounds include the chirp of a baby bird, the bah of a baby sheep, even the crying of a human baby are all much higher in pitch than their adult counterparts. This higher pitch signals to the others more easily the signals of need and requests for attention and is understood to have direct connections to the emotions in the adult as shown in empirical studies on pitch [7]. When our mind processes visual cues and recognizes faces and emotions, there is a message of context and intent which is understood. For example, a smile means "I am happy and approachable." This is an association we make very early in development, and it helps humans navigate the social world. In a similar way, when the brain processes auditory signals, the perception of sound calls the person to identify and understand the symbols behind the stimulus. Most objects in nature which are cute and happy transmit higher frequency sounds. Of course, some exceptions apply here as well, including bats, eagles, and other animals who use the special properties of increased propagation of higher frequencies.

9.5.6 Size and Proportion

In this test, users were presented with a paper survey and were asked to show their preferences for size, proportion and association with "cuteness." In the first section, the respondents were presented with three different scenes containing several objects. Users were asked to select the scene showing the object in its size that was the most "cute." This same test was repeated for each of the other objects in the scene. During the test for each object, other objects in the scene remained in the original sizes. The results of this test showed a preference for changing the size of the object to be small in relation to the other objects. An example of the results which were taken is shown in Fig. 9.6 where respondents reported that a smaller sized flower in a scene was cuter than the larger sized flower.

An additional type of proportion test was also presented, involving various ratios of two parts of an object. Respondents were provided with characters including a human, a cow-like animal, and a mushroom. For each character, there were four proportions presented. Users were instructed to choose the picture of the figure that was the most "cute."

The objects which the respondents were presented with and the indication of the two sections noted as "head" and "body" sections are shown in Fig. 9.7.

The respondents selected proportions that were similar to the proportions of a baby, in which the head is disproportionately larger than what is natural in relation to the size of the body. Our description of cuteness is consistent with the emotions of the nurture response and the resulting selections by the respondents confirms the definition and agrees with theories of the nurture response of Konrad Lorenz [18]. In

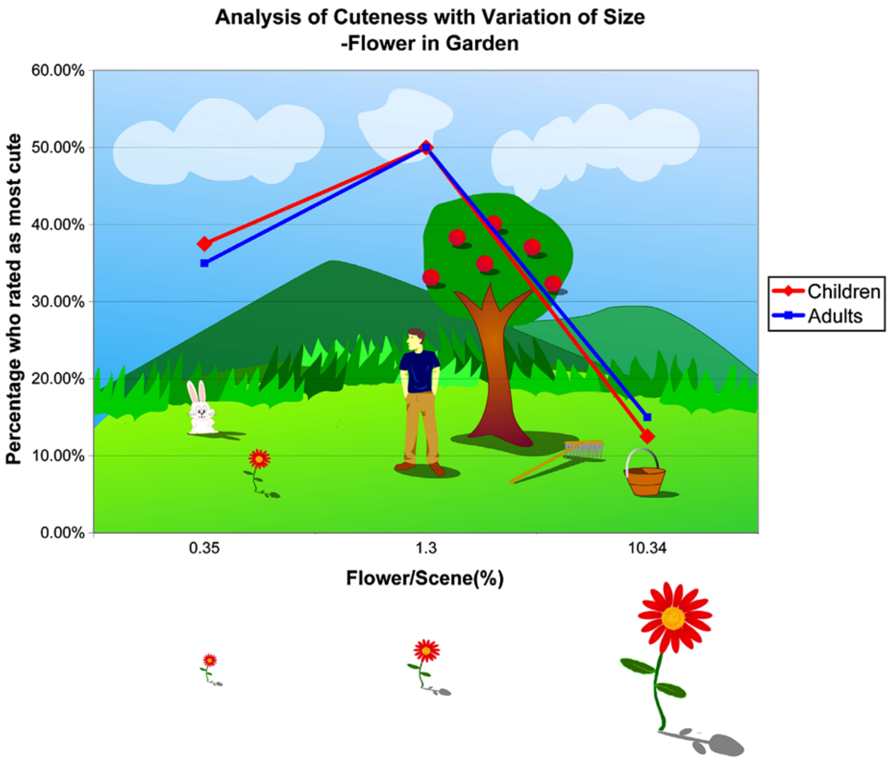

Fig. 9.6 Diagram showing the difference in the preferences for flower size between the adult and child respondents

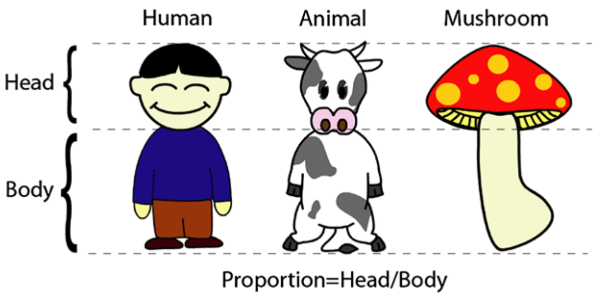

Fig. 9.7 Diagram showing the Head and Body sections of the objects whose proportion the user manipulates

our studies, we found some differences in user preference by the older and younger respondents. For example, adults showed some tendency in selecting proportions of a larger head as shown in Fig. 9.8, yet in the selection for proportions of the cow-like character, the adults selected a smaller head (0.64 proportion of head/body)

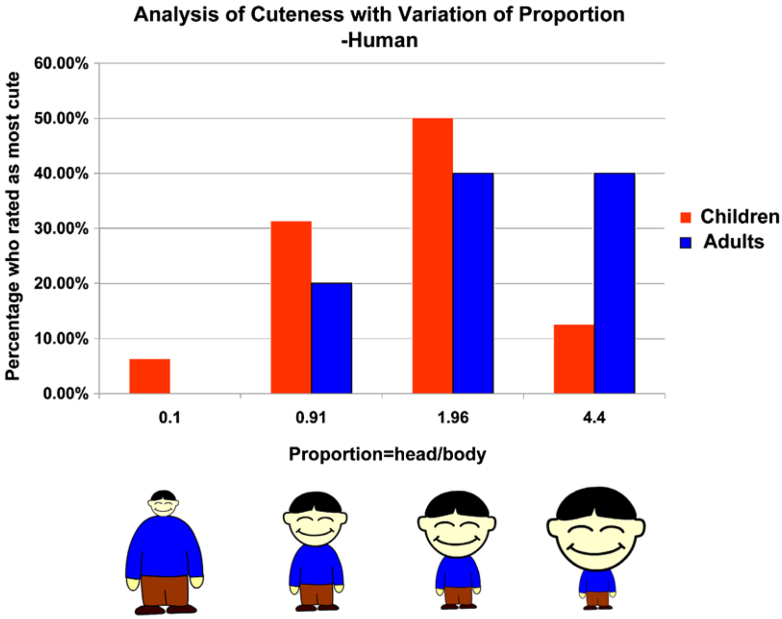

Fig. 9.8 Diagram showing the ranges of proportion selected for the human character

than the children respondents as shown in Fig. 9.9. In the proportion selections for the mushroom, both age groups selected in a similar way to each other as shown in Fig. 9.10.

9.5.6.1 Why Are These Proportions Cute?

With most respondents selecting for the proportions showing a clearly larger head, the connection to the proportions of a baby are natural metaphors. The difference in selection for the cow character in which the adults chose a smaller head, we may need to do more testing, but it might be that the adults prefer to see the proportions that are more natural and less exaggerated for certain characters or animal species. We will explore other animals in the future to determine if there are additional trends unique to mammals and the unique perceptions of the other phyla.

9.5.7 Shapes and Form

We presented the respondents with simple shapes and instructed them to choose the shape which is the most cute. As shown in Fig. 9.11, the preference for roundness

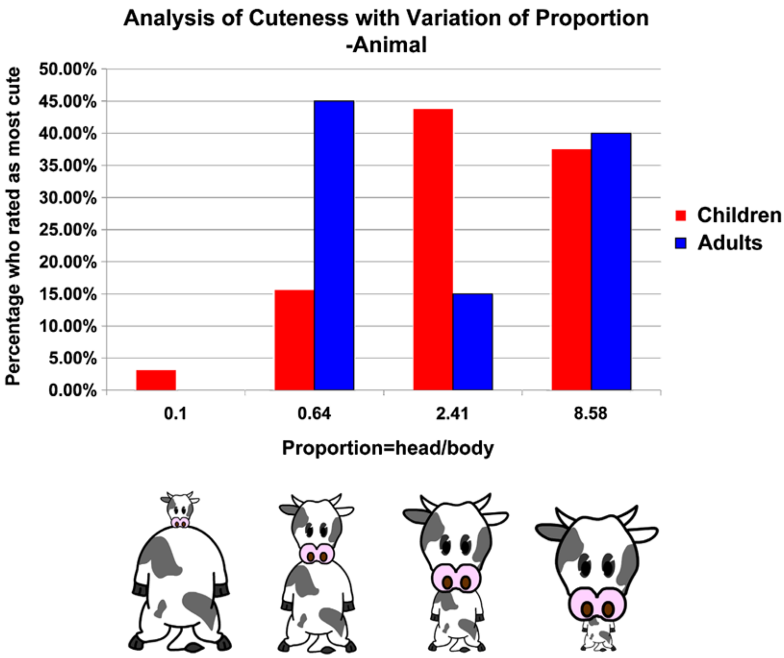

Fig. 9.9 Diagram showing the ranges of proportion selected for the animal character

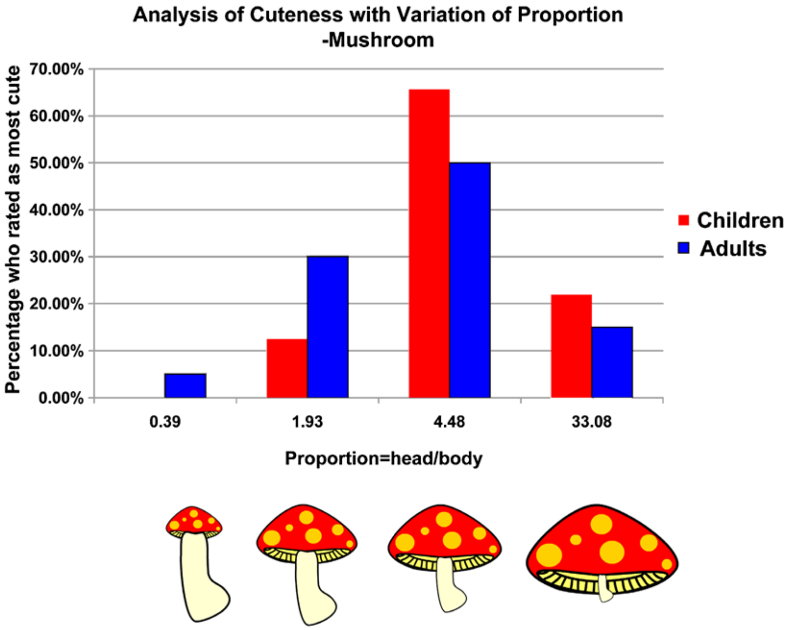

Fig. 9.10 Diagram showing the ranges of proportion selected for the mushroom

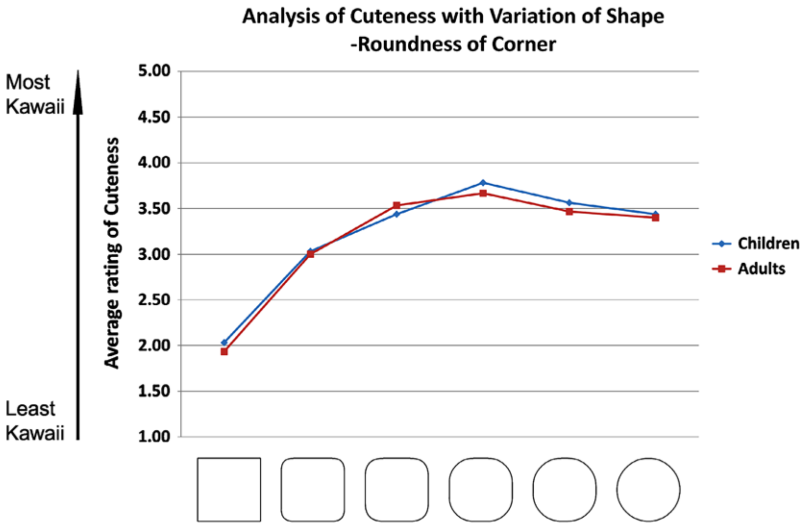

Fig. 9.11 Diagram showing effect of roundness of corners on cuteness

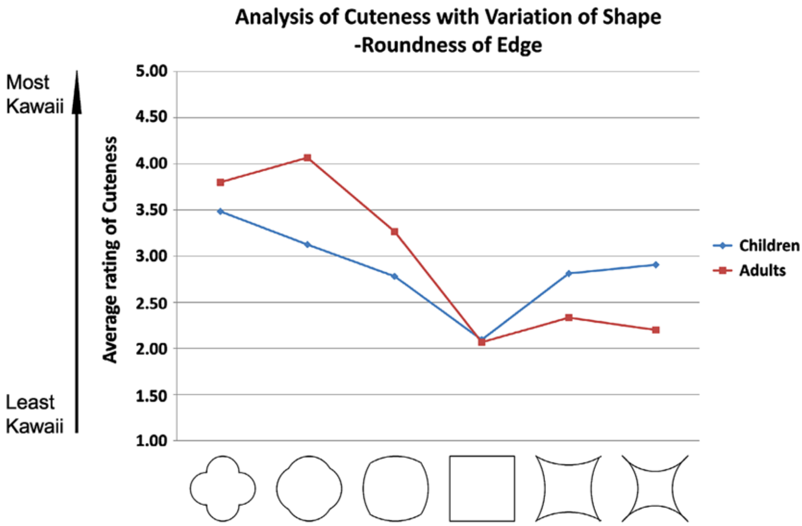

Fig. 9.12 Diagram showing effect of roundness of edge on cuteness

is consistent. There was an interesting result as shown in Fig. 9.12 in which the younger respondents selected objects with sharper edges, possibly due to reading into the image as being more like a star or another symbol.

In Rudolf Arnheim's research, there is much focus on the psychology of shapes and perceptual forces, and he describes the concept of the circle as conveying the infinite and purity [4]. This could give good reasons why we associate cute and orderliness with this. On the other hand, too much order and sharp corners lead to disinterest or a challenge to restriction.

9.5.8 Smell and Taste

So far, there has been no formal research to measure the cuteness of smells scientifically, although there are a number of cute toys and fancy goods that smell nice. The specially intertwined chemical senses of olfactory (smell) and gustatory (taste) have a very short and simple connection to the brain and the exact functioning of the parts including the olfactory bulb are not fully understood. It has been shown, however, that memories can be tightly ingrained in the long term memory if accompanied with stimulation of the sense of smell. Future research can help to reveal the brain activities related to interactive experiences focused on cuteness.

9.6 Related Works. Cute Interactive Systems

It serves well to look at other interactive systems that utilize the cute aesthetic as well. We now briefly review some of these more recent works.

Topobo [29] is a 3D constructive assembly system with kinetic memory, the ability to record and playback physical motion. Unique among modeling systems is Topobo's coincident physical input and output behaviors. By snapping together a combination of Passive (static) and Active (motorized) components, people can quickly assemble dynamic biomorphic forms like animals and skeletons with Topobo, animate those forms by pushing, pulling, and twisting them, and observe the system repeatedly play back those motions. For example, a dog can be constructed and then taught to gesture and walk by twisting its body and legs. The dog will then repeat those movements and walk repeatedly. The same way people can learn about static structures playing with building blocks, they can learn about dynamic structures playing with Topobo.

Crickets [30] are small programmable devices that can make things spin, light up, and play music. Users can plug lights, motors, and sensors into a Cricket, then write computer programs to tell them how to react and behave. With Crickets, users can create musical sculptures, interactive jewelry, dancing creatures, and other artistic inventions – and learn important math, science, and engineering ideas in the process. Crickets were designed especially for making artistic creations.

Papero [28] is a prototype robot developed at NEC's Central Research Laboratories. Using visual recognition, voice recognition, mechatronics and Internet communication technologies, the robot can recognize individual faces, understand verbal commands, and move smoothly around the home, avoiding such obstacles as tables and chairs.

KKobito developed by a team of Tokyo Institute of Technology is a digital agent, which instills a sense of wonder augmenting the digital world, yet interacting and influencing the physical world even when they are invisible. Because they are not as predictable as robots, they bring a sense of warmth that a real companion gives and can act in surprising ways.[2]

Unazukin developed by Prof. Watanabe of Okayama Prefectural University also provides a warm feeling in the form of an interactive doll toy, which answers with a simple nod or shake of the head to questions spoken to it. Although it is a very simple embodiment of AI, the illusion of a personality is perceived and the personality of the character captures the simple feelings of cuteness.[3]

9.7 Cute Engineering

Engineering is the application of technical and scientific knowledge to solve problems. This is very closely related to design work, and, in fact, design is one of the tasks of the engineer. Our focus is more closely related to testing and exploring the concept of cuteness as a means to activate cognitive structures, emotional responses, and user behavior, so we have chosen to call this vector of research, "Cute Engineering" instead of just using the more simplistic title of "Cute Design."

9.7.1 Cute Filter

Part of our focus is to uncover the influence of elements in the cute interaction and quantify as much as possible. This will enable the digital representation and manipulation of these elements. Therefore, the results of the perception studies can be applied to the creation of new interfaces and objects and could allow for automatic transformation of inputs and outputs into a new and possibly unexpected result in a sort of "cute filter."

The shift to user experience design focus emphasizes the importance of aesthetics and form over function. Consider as an example the iMac, which was virtually the same computer as previous versions but with an added stylish cover, which persuaded traditionally non-computer users to buy into the world of computing, and hence sold more units. We propose a series of cute filters that take advantage of the 'cuteness' factor, transform inputs from the user or environment, and provide a digitally calculated output which appeals to the user (see Fig. 9.13). Using a cute filter, users can freely choose the cuteness parameters such as color, size, motion, smell, and taste to adjust their desired cute output. The cute filter converts the sensor input and sends it for actuation. We propose five filters which are based on the five human senses. We aim to decompose each sensory cue (visual, audio, tactile, smell, and taste) into individual streams of digital values. Similar to the way in which a

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[2] http://www.siggraph.org/s2005/main.php?f=conference&p=etech&s=etech3.

[3] http://rainbowspice.jp/unazukin/index.html.

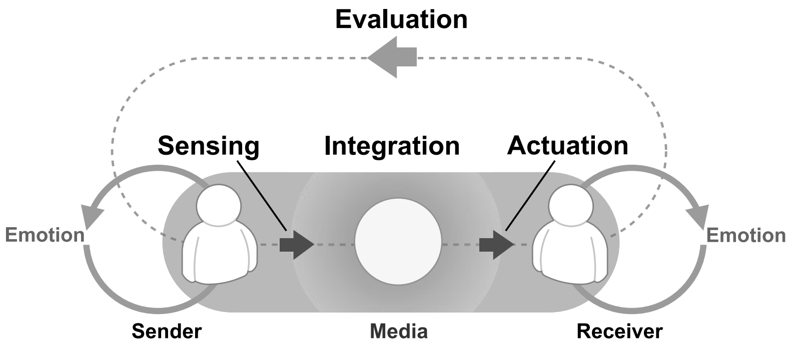

Fig. 9.13 Architecture of cute filter

sound equalizer adjusts the components of audio, the cute filter can boost the color, texture, shape, taste, smell, or motion in the output via the automatic processing and deliver happiness with individualized precision. Our research seeks to uncover the meaningful aspects of sensory perception which can be manipulated to increase the cuteness factor. Our vision extends to building novel modules such as tactile sensors and actuators for texture processing. Present research addresses the texture sensing for only a selected amount of textures. But our research will mainly focus on feeling the different kinds of textures. It also widens our research areas in to developing a tactile glow such that when you wear it and use the glow to touch textures, you can feel different touch feelings (ranging from hard and cool, to soft and furry). Such research of texture sensing and actuation presents immense technical challenges which may include even some degree of bioengineering or a fusion of miniature cameras and pressure sensors for a clearer sensing and actuating. This also broadens our research in to the areas tapping the physiological aspects of the human brain that controls the touch senses of human anatomy, smell and taste. In addition to the challenges presented above, the devices are required to be of high speed in regards to performance, especially when combined with cute filtering. Our research on smell and taste filter will develop a real-time cute smell/taste changing device which can be used to create a cute fragrance automatically to replace uncomfortable bad smells. The research will aim to conclude what are "opposite" smells to produce for smell the technique similar to noise cancelation headphones for sound. In the research, we will address the taste-reconstructing device which is used to reconstruct the perception of a taste by stimulating the taste buds using actuating mechanism. Also we propose empathetic media, using elements of cuteness to appeal and motivate users, present surprising elements, build relationships with them, and leave them with positive feelings.

If we imagine that such a cute filter exists, then the adjustment of the cute factors would need to be tailored to the individual user preferences and perceptions. We can consider the calibration of a joystick as a metaphor for this process of adjusting to the user. When we plug in a joystick, we have to test the extremes along the x and y axes, after which the system understands the nature of the joystick and its limits. The same could be said for other perceptions, for example, cute. We can think of an applet in which the user is asked to reorder some objects from most cute to least cute. This could be on the spectrum of colors, or on movements, etc. Then, after this simple calibration exercise, the system understands how to set the variables in the cute filter. Not only does this have good uses for the initial setup of the understanding of this unique user regarding cute, but it allows for similar testing and calibrations for other emotions, for example, scary, or happy, etc. Then, throughout the system, the ongoing "tweaking" of this calibration takes place based on the user choices.

9.7.2 Research-Oriented Design

The next step to develop and refine the cute engineering approach is to create applications which are based on our Cute engineering research and in a research-oriented design approach, to explore the human interaction and experience issues. In order to conduct this research, two open platforms are being developed, a 3D virtual world for social networking and a small portable robotic interface to the virtual world. These systems will provide a platform to conduct user studies which will explore general user experience issues, but more importantly, the strengths of cuteness in our contemporary world. Research questions include large social issues, for example, 'How can cuteness reduce aggression in online communication?'. This and other research questions are being answered through ongoing user studies with the prototypes.

9.8 Qoot Systems. Petimo and Virtual World for Social Networking

Social networks are becoming the latest trend for online communication and making new friends, while helping people keep old friends in close contact. With the expansion of digital media, the attraction of teenagers and younger children to social networks and other activities in the cyberworld is growing. However, cyberspace is becoming an unsafe and more exploited environment, especially for children [6]. This results in conflicting messages between parent and child, social isolation, and communication with unknown online people with unverified identities [38]. Psychologists have theorized about the meaning of online relationships during adolescence, and have warned about the dangers of sexually exploitative online relationships [38].

The motivation behind this research is to provide a safe path for children to make friends in online social networks. "Petimo" (see Fig. 9.14) is designed to protect children from potential risks in the virtual world and help them make a network of friends in the real and virtual worlds. The name is a combination of "Petit," meaning *small* or *little* in French, and "tomo," meaning *friend* in Japanese, which resembles a small friend. It is a small RISC (Reduced Instruction Set Code) microcontroller

Fig. 9.14 Petimo

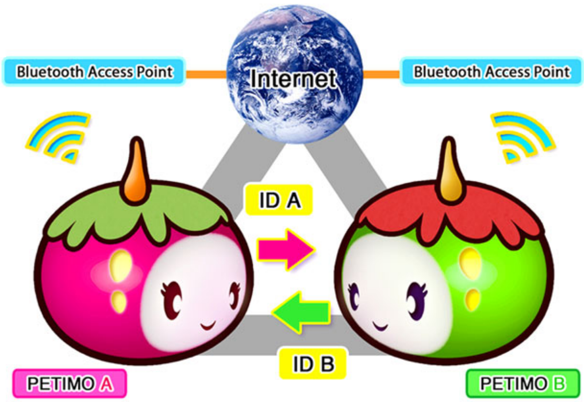

Fig. 9.15 Physical friends adding feature

based robot that includes a close proximity RFID based contactless friend identification and exchange function as described in Fig. 9.15. This adds a new physical dimension to social networking through physical touching of the robots to authenticate new friends through a centralized database. The physical touch requirement will help prevent malevolent adult strangers being added as friends, and allowing children to fully exploit the new digital social world. In addition, with the system, children experience enhanced relationships with their friends through interactions in the real and virtual worlds by sending gifts and emoticons mediated by their robots with haptic, visual, and audible events.

Children can add friends by selecting the "Add Friend" option on Petimo's menu and touching their friends Petimo. This results in exchanging of a unique 64-bit identification key between two robots and simultaneously sending this event to the online user verification system for authentication. Upon successful authentication, the relationship between the two friends is established. The user input sensing mod-

Fig. 9.16 Petimo-World together with Petimo

ule includes a smooth scrolling enabled capacitive touch sensor pad, primarily for child-friendly menu navigation. With the pressure activated squeeze areas of the robot surface, not only messages but also hugs and gifts can be sent over to other Petimos. This novel conceptual robot design comes with a full colored miniature OLED graphics display, an embedded sound synthesizer, and an embedded vibro-tactile effect generator. These features enable a rich interaction between a Petimo and the user which includes a multimodal engagement feature not only audibly or visually but also tactually.

In futuristic scenarios, Petimos may be extended to any social network in order to create a safe and secure interactive environment for children. As a proof of concept, we have developed a 3D virtual world, "Petimo-World," which demonstrates all of the realizable basic features with traditional online social networks. Interactions are furnished through Petimo in both online and offline modes, thus acting as a tangible extension towards a more meaningful social network experience (Fig. 9.16). Petimo-World is primarily focused on social interaction and cultural education, oriented towards youth and family, extending to harmonize with the society.

For instance, two children will not only be able to add friends securely, but they can also play with their own Petimos or interact with friends directly (see Fig. 9.17) by squeezing the device. Petimo allows children to easily exchange personal thoughts and feelings with friends. In another scenario, parents can be relieved that their children are in a safer online environment by monitoring the activities of their children and being comfortable with the physical interaction which enables a two-factor authentication model including a parental authentication module, which overcomes the traditional security hole of other social networks. Parents can also build a closer relationships with their children in the virtual world, which is more familiar to children, by exchanging virtual gift items.

Fig. 9.17 Two children interaction with Petimo

There are mainly three kinds of interactions in the overall design:

1. Petimo to Petimo Interaction
2. Petimo to Petimo-World Interaction
3. Petimo-World to Petimo-World Interaction

Except for the last mode, it requires the presence of a physical robot, Petimo. Exchanging gifts and sending messages (predefined emoticons only) in Petimo-World are then sent to the Petimo. By default, all interactions are copied to the Petimo and Petimo-World at the same time.

Technically, it consists of several main modules. A high level system illustration is given in Fig. 9.18.

9.9 Sensing, Actuation and Feedback

Unlike existing software extensions to social networks, Petimo provides a physical extension which expands the multimodal engagement not only audibly or visually, but also tactually. Considering humans strong positive bias towards physical touch [8], a squeeze and touch sensing mechanism has been added as the primary input sensor. To ensure the rich content and feeling delivery, for actuation,

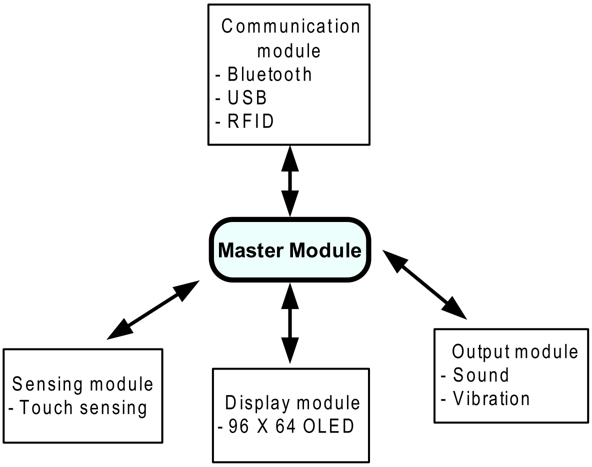

Fig. 9.18 System overview of Petimo

vibrotactile effect generators, sound output modules and OLED display have been used. The following sections will provide details about sensing, actuation and feedback.

9.9.1 Sensing

9.9.1.1 Touch Sensing

Petimo targets typical users as children of ages 7–9. When a system is being designed for the children, it is necessary to pay careful attention to their interpretation of objects and interactions. Important considerations were taken into account when designing the menu with less complexity, the outer shape with that is more cute and easy to fit into a child's palm, easy operation steps, smaller size and lesser weight.

Petimo menu is used for scrolling through friends, sending gifts (see Fig. 9.19), sending emotions (see Fig. 9.20), etc. Menu navigation design was done considering the easiness of use for children and to provide a new interactive experience of menu navigation. Initial design considerations were focused on having a scrolling switch or jog dial. However, a touch screen type menu navigation was found to be less complex and easy to use for children due to touch screen's [2] direct menu manipulation.

A jog dial menu navigation, which is an indirect manipulation of the menu items, does not provide the user with a clear relationship about what exactly he or she is doing. But, in this touch sensor, a child can actually place his/her finger on the menu and move the menu to the direction he wants. And he can see the changes he has made in real time as the menu moves. Thus, the touch sensor based controlling of the robot will allow the child to easily relate his actions. Secondly, to preserve the cuteness of the robot, we have eliminated the input mechanisms such as scrolling switches or jog dials which disturb its cute look. Finally, the use of touch sensing reduces the size of the design space in the robot.

Fig. 9.19 Gift menu

Fig. 9.20 Emoticon menu

9.9.2 Actuation and Feedback

Petimo would be less interactive if it did not have a good feedback mechanism. Thus, a touch enabled OLED display, vibrotactile effect generator and a tone generator have been used to enhance the user experience through continuous touch feedback.

9.9.2.1 Display Module

The display module is an important media for interacting with users. It transforms digital and analog information into visual spectrum. Visualized information and the related user-interaction techniques have the advantage of being simple, fast and straightforward while transmitting the abstract and large amount of data into human perception. Especially the graphics display is more convenient, quicker and direct for users to easily digest the information exchange.

Fig. 9.21 Gift notification

Fig. 9.22 Different emotions display

We now outline the core functionalities of the module:

- Robot's display module aims to visualize emotions through gestures and animations on the mini, low cost, energy saving color Organic Light Emitting Diode (OLED) [27] display. That is to express the user's emotions, such as happiness, sadness, and love, to the another user by displaying facial animations which can be more lively and intuitive for users than reading texts. For example, a user, say, John, knows that Jane did well on a school exam, and can send his happiness by sending a joyful facial animation. The visualization of joy can express John's emotion to Jane more clearly than only sending text messages.

  Figure 9.21 shows one example of the cute elements display. A user, say, Jeena, sends a gift to her friends. The message *Milk from Jeena* will be displayed on the screen. When Jeena's friend receives the gift, he/she can choose to ignore or to reply with another gift in return. This is meant to increase the interaction between users.
- The display module is used also for setting up a simple interface for the user to manipulate the robot. For example, a scroll menu is used to display a friend list, and the user can select the friend with whom he/she wants to communicate. It is associated by touch sensing.
- The display panel is the face of the Petimo (see Fig. 9.22). Therefore, by changing the display, it is possible to express different emotions in the robot. Figure 9.22 shows the different display animations for different emotions. For in-

stance, Fig. 9.22(a) presents the image for the happy feeling. It is possible to show a number of emotions similarly, adding fidelity to the degree of emotions and giving rise to the resolution of feeling it can handle.

9.10 Conclusion

In this chapter, we have taken a look at the cultural phenomenon of cuteness, exploring its possible historical beginnings and the impacts on popular design. As with other attempts at emotional design, "cute engineering" seeks to capture the essence of human feelings and emotions in order to understand ways to motivate, engage and shape the user behavior in a positive way. We have presented some recent empirical studies into user perception of cuteness and have shown the transferability from the 2D paper realm of the manga through to the 2D world of websites, the 3D onscreen world of Virtual worlds, and on to the 3D real world involving robots.

In a more radical approach, we entertain the idea that the users of today and tomorrow are in a process of co-creation of their experiences in the virtual world and of their realities in general. We have shown examples of how users can share in the co-creation of cute and gain a sense of belonging and happiness in the world. Although the focus of the research presented in this chapter is based on cuteness, the individual concepts gleaned from this process can be widely used in other contexts. For example, the same rigor can be applied to the emotional feeling of "safe" or "smart" for that matter, with possible outcomes being radical new interfaces which could not have been imagined before extending its capabilities to fundamentally change social networks and providing a novel approach to helping children make friends easily in a more protected and safe social networking environment.

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Chapter 10
Designing for Entertaining Everyday Experiences

Masa Inakage, Takahiro Arakawa, Kenji Iguchi, Yuichiro Katsumoto, Makoto Katsura, Takeshi Osawa, Satoru Tokuhisa, and Atsuro Ueki

10.1 Introduction

Entertainment is one of the essential elements in the human society. It can take various styles, not limited to film, game, music, theme parks and other established forms of entertainment industries. Entertainment includes "fun" in our everyday life activities, from meeting friends to relaxing at hot spas [20].

Everyday artifacts can become entertaining media if these artifacts and environment are designed to be responsive. Responsive everyday media is starting to appear as smart toys and intelligent environment, but it can be extended to affective furniture and entertaining household artifacts [3].

This chapter discusses the researches of entertaining artifacts based on the vision of Ubiquitous Content. Ubiquitous Content is defined as content for living people, which bonds closely with life, proposing how future things can become affective and amusing with pervasive and entertainment computing technology. Content is experienced through interaction between people, artifacts and the environment, all existing in the real world.

The interaction with responsive everyday artifacts and environments must be natural, without the use of special devices and controllers. Body gestures and movements can trigger the artifacts to perceive the users intention. Embodied media is becoming the trend for interaction design in gaming platforms and mobile devices [19]. Embodied interaction can be deployed to Ubiquitous Content. We use body interaction to communicate, and combine our various senses including smell and taste to capture and understand information surrounding us.

Sensuous computing is an emerging area, uniting computing engineering with creative aesthetics, from digital arts to media design, and integrating the five senses into the design. To make use of our five senses, entertainment devices now have vibration to communicate with the user in the tactile language. Most of the current

M. Inakage (✉)
Keio University Graduate Schoool of Media Design C6S06, Hiyoshi 4-1-1, Kohoku, Yokohama, Kanagawa, Japan

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mobile phones are equipped with vibration feature (in Japan it is called Manner Mode) so that the user can be notified receiving calls and emails with vibration instead of ringtone sound.

Network connectivity is now a widespread and essential component in our modern living style. The use of the Internet as well as pervasive computing technologies needs to be taken in to account in the design of everyday media [23]. The exploding popularity of social networking services such as Facebook, Flickr, MySpace, Second Life, and many others has brought the Internet to the next level as a social media. We rely on cyber-society to entertain ourselves, in a similar manner that we go to cafes and pubs.

The use of network is also a common ground for gaming. There is a big shift from standalone games to online games. Games are played by multiple players, becoming a platform for social and collaborative entertainment. Games are pushed further to use both the cyberspace and the physical space. Pervasive gaming started as an area that has been explored by research institutions, and evolved to commercial games as the so-called Alternative Reality Games. The key to the emerging network-based entertainment is that it is designed to connect people through network technology. It is the collective media.

This chapter guides you through the four emerging media for designing entertaining experience in our daily life with pervasive computing: everyday media, embodied media, sensuous media, and collective media. Each media will present research results to share how interaction design and technology design are tightly coupled in the design of Ubiquitous Content.

10.2 Everyday Media

We are surrounded by household artifacts in the daily life. Many of the artifacts expect us to interact and operate. Each interaction design differs so that we are starting to get overwhelmed to remember their operation procedures. Maeda suggests that we return to “simplicity” (Maeda) [11]. “Simplicity” does not necessarily mean fewer features, but it is the simplicity of interaction design that is the key to the design of everyday artifacts. It is about whether we can interact with our natural instinct, to become transparent.

Everyday media turns everyday artifacts and environment to be reflective and entertaining [12, 21]. Norman suggested that “smart” and affective artifacts and environment should be carefully designed to interact with our natural instinct so that they are emotionally attached [15, 16].

Everyday media shares its vision with researches in ambient media and ambient intelligence. Ambient media was proposed by Tangible Media Group led by Hiroshi Ishii at MIT Media Lab in a series of their works such as pinwheels, ambientROOM, and musicBottles [8–10, 24], Ambient Intelligence (or AmI in short) initially began as a research activity at Philips and currently evolved to an international community to pursue the area of immersive and intelligent interfaces for everyday media [18, 22].

Fig. 10.1 Amagatana

Fig. 10.2 Tabby

There are two projects that were carried out at Keio University imgl Inakage Laboratory for Digital Entertainment: Amagatana (Fig. 10.1) and Tabby (Fig. 10.2). In the following sections, each project is presented to show how everyday artifacts can be designed for affective and entertaining experiences.

10.2.1 Amagatana

Amagatana is a mystical sword for enjoying the blithe feeling after the rain. At a first glance, Amagatana seems to be just a plastic umbrella. However, when you swing Amagatana, the magic begins and the user can hear the sound of swords clashing from the headphone.

10.2.1.1 Interaction Design

The embodied interaction design is simply to swing the umbrella. This simplicity is important for everyday media because everyday media also serves as useful everyday things. Amagatana will be used as an umbrella when it is raining, but the added magic of embodied interaction creates the entertaining experience. Thus, designing entertaining experience with everyday media differs from entertainment gadgets in that its purpose is entertainment.

There are three kinds of swings: weak, medium, and strong. The direction of a swing also contributes to the variation. Amagatana detects how strongly the user swings, and its direction such as downward swing and upward swing. These swings are translated into different types of sounds as “Basic Swings” sounds. The combination of swings creates five kinds of “Special Moves” to generate “Special” sounds.

10.2.1.2 Technology

Amagatana consists of the plastic umbrella with an embedded dual axis acceleration sensor and an external sound player. The sensor inside the umbrella measures inclinations of holding up Amagatana and abrupt accelerations given by the players swing. Thus, both the angle and speed of the swing can control the sound. The measured data is sent to the sound player through USB.

10.2.2 Tabby

Tabby is an interactive room lamp that coexists as a lamp as well as ambient entertainment content. It continuously breathes while being on and this feature sometimes gives an impression as if it is alive. Tabby consists of a furry, soft fabric lampshade so that it gives an impression of a pet.

10.2.2.1 Interaction Design

It has an ability of interaction by the motion of its lampshade and the intensity of light. It is designed for both direct and indirect interactions. The direct interaction is corresponding with the reaction of illumination to the touch of user, and the indirect, ambient interaction is continuous motion of breathing with a change in its pace. This indirect interaction occurs according to the frequency of user’s touch and the environmental noise. The design intention is to maintain the subconscious connection between human and content by designing the seamlessness between direct and indirect interaction.

10.2.2.2 Technology

Tabby has two embedded sensors for acquiring data. One is a microphone to get the environmental noise for detecting a condition of the place where the lamp is placed. Another is pyroelectric infrared sensor inside the lampshade to detect the significant deformation of its lampshade. It is used to detect the timing of touch by a user by monitoring the deformation of the lampshade.

For the actuation, Tabby cycles its breathing motion by expanding and shrinking the soft lampshade, by controlling the circulation of air. The microcomputer controls the rhythm and intensity of the fan. The rhythm of breathing is about 50 times per minute. It is based on a pace that is a little slower than the breathing of typical people. The breathing speed changes in relation to the environment state detected from the two sensors.

10.3 Embodied Media

Embodied media is about the use of body movement and body information for interaction with the computing environment. Dourish first introduced the term “embodied interaction” to define the physical interaction with computer systems [5].

Recently, commercial game products started to shift from controller-based interaction to interactions using the entire body movements. The embodied interaction provides natural user interface because we use gestures and body motion to communicate with each other in our everyday life activities. Games such as Guitar Hero and Dance Dance Revolution are typical examples where your body movements are translated to your input information for game playing [1]. The body movements are designed in such a way that they resemble the real guitar playing and dance steps, respectively, but much simplified so that novice users are able to experience the fun of playing guitar and dancing on the dance stage.

More recently, the embodied interaction is deployed to the devices such as Nintendo Wii game console [14]. Due to Wii’s commercial success, some mobile phones in Japan have sensors embedded for embodied games offered for mobile phones.

Pervasive games are also based on body movements for playing games. In pervasive games, the users are expected to use big play field such as a park or even a city. Users run and walk in a similar manner that children play in the field. An early example is called “Can You See Me Now?” by Blast Theory [2]. The game combines both online and physical streets. Players on the streets are tracked by GPS, and players online can participate anywhere in the world.

A classic game Pacman is redesigned for Pervasive Games in two cities. Human Pacman used augmented reality technology to play on streets in Singapore [4]. In Pac Manhattan, the streets in Manhattan, New York City, became the play field of Pacman [17]. Players needed to run within the city streets to enjoy the game.

In the following sections, two examples of embodied entertainment are shown that extend the game entertainment to general play and communicative entertainment.

Fig. 10.3 Morel

10.3.1 Morel

Morels (Fig. 10.3) are ball-like outdoor toys for children, which facilitate the emergence of new forms of physical play. They are ball-like objects that come in sets of two or more. In addition to allowing actions like kicking or throwing, they endow players the ability to know the existence of other Morels in the vicinity, and to remotely make other Morels jump. This networked toy is an emerging genre of gadgets that gadget-to-gadget communication introduces for new ways of thrilling entertainment.

10.3.1.1 Interaction Design

Morel introduces an important concept design to playful gadgets, namely, transmission range. Morels operate in sets of two or more. When a Morel enters other Morels' vicinity, they alert their holders by emitting a sound. A player can also squeeze his Morel to "charge up" other nearby Morels. This will cause the other Morels to emit a rising tone, which then changes to a siren wail when they have been "fully charged." When the charging player lets go and squeezes again on his Morel, the other Morels will kick the ground with a spring-loaded stick and perform a small jump. If a Morel leaves the vicinity of other Morels while they are being charged, their charge resets to zero. This transmission range is invisible to the players, but the players will start to sense the range of vicinity, and as a result players will keep running the field to control the distance between other players.

10.3.1.2 Technology

Morels are designed to transmit and receive wireless signals by an ad hoc network. Each Morel operates in five modes: Out of range, Within range, Charging, Fully charged, and Launching. If the Morels are located within the vicinity, both Morels switch to Within range, but if they are not in the vicinity to detect the signal, the Morels switch to Out of range mode. When a Morel is receiving a "query" signal from another Morel, the Morel enters Charging mode. For each query signal received, the Morel increments its internal charge value variable by the amount proportional to the radio strength of the received signal. Therefore, the closer the sending Morel, and stronger the signal is, the faster the receiving Morel charges. When the charge value exceeds a set amount, it switches to Fully Charged mode. When the Morel in the Fully Charged mode receives a launch signal, it will enter Launching mode and will immediately start the launch sequence and finally sets off the spring-loaded rod to jump.

10.3.2 MYSQ

MYSQ is a video booth where the user can film his or her very own dance video clip and send it to friends. To create a compelling video clip, MYSQ allows the user to add visual effects and sound effects in real-time by simply dancing in the booth.

10.3.2.1 Interaction Design

MYSQ (Fig. 10.4) is designed as a natural interaction using multilayered, embodied interaction. Multilayered interaction is realized by the combination of the video effects via foot sensors and the effects parameters assigned to the player's arm motions. Each foot sensor is assigned an independent video effect and sound track. The effects parameter is derived from absolute arm movements via image analysis. Thus, the footstep determines the visual looks and the speed of the arm movement controls the parameters, replacing the control switches and slider bars.

10.3.2.2 Technology

There are 6 types of visual effects that are assigned to foot switches. In addition to these default visual effects, there are several others such as particle or strobe effects. These special effects are triggered when a specific sequence of steps has been entered; the special effect is then superimposed on the normal effects.

The player wears a MYSQ ring that has a high intensity red LED light. The LED light is tracked by the video camera to sense the player's arm movement. Real-time image processing analyzes the light and color information and plots it on a 2-plane to calculate the optical flow.

Fig. 10.4 MYSQ

10.3.3 livePic

livePic (Fig. 10.5) is an interactive, embodied drawing board which expands the drawing experience. It enables the user to "move" and "control" the pictures that are drawn. Therefore, livePic will change the interactive relationship between drawing and the users physical action. A fundamental concept of livePic comes from the idea in which drawings suddenly move as if they are alive, often seen in scenes from classic movies or cartoons.

10.3.3.1 Interaction Design

The goal of the interaction design of livePic is to develop an embodied drawing system and interactive display through intuitive and direct interaction. The main

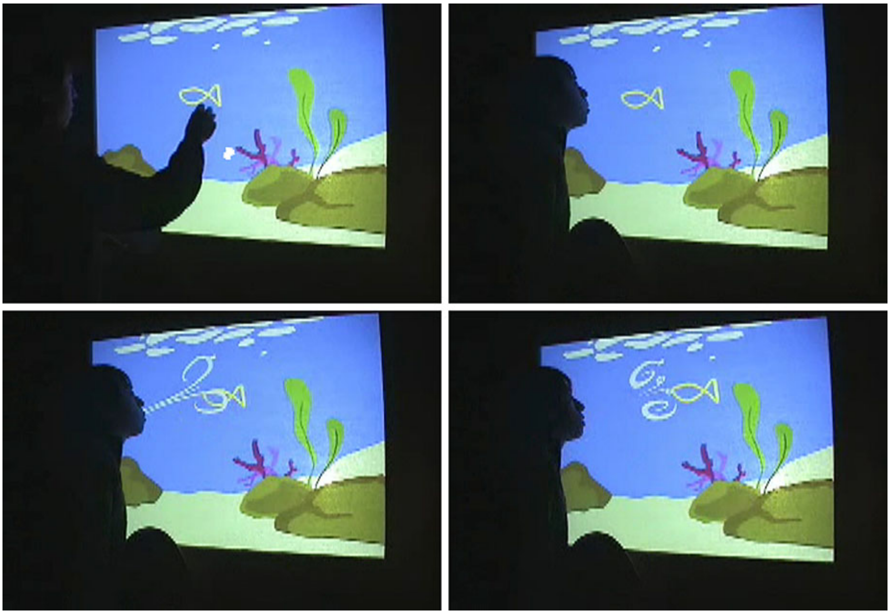

Fig. 10.5 livePic

features of this design are the user-friendliness, simplified interaction, object recognition, and the potential communication and collaboration during the process of creation. livePic adopts individuals breath as the interaction method. At a first glance, livePic seems like a simple painting canvas that can draw pictures using the paint brush, but actually livePic enables the drawn objects to become animated once you give breath to the picture. Users can interact with their own drawings through the individuals breath.

10.3.3.2 Technology

The user draws a picture on the paper screen with an infrared LED embedded electronic pen. The web camera behind the screen tracks the movement of the pen and the controls the drawing. Unique IDs are embedded on each pen, and the colors and functions of each pen vary respectively. Additionally, there are various sensors around the screen. The drawing is displayed using the rear projector. Once the drawing is completed, the user can interact with the drawing by blowing onto the screen. The heat sensor in the back of the screen monitors the temperature change of the paper screen. The temperature of the area near the picture increases by the breath heat.

10.4 Sensuous Media

Sensuous media involves our five senses: vision, hearing, tactility, olfaction, and taste. There are many previous researches and entertainment works in sensuous media using some of the combinations of five senses.

Technology related to tactility has been researched in relation to virtual reality. Force feedback is now a classical example that introduced tactile experience through controlling the interface device that changes its smoothness of its movement. For example, when we want the user to experience touching a solid wall, the device is controlled to tighten the gear so that as soon as the device hits the virtual wall the device cannot be pushed further. Today, our mobile phones are equipped with vibration feature to notify the user as an alternative method to sound.

An example of recent researches in tactile technology is Gravity Grabber. It uses a wearable haptic interface that creates weight sensation of virtual objects when a virtual object is grabbed. This sensation of weight enhances the reality in the virtual space.

The technical challenge of creating olfactory experience is its difficulty of smell control. Once a scent is emitted into the air, the scent diffuses. The challenge is to have a tight control so that the scent only stays within a desired area. Another challenge is to erase the smell.

SpotScents realizes localized olfactory experience by shooting scent balls with a scent projector [25]. The scent projector tracks the human movement so that it can accurately emit the scent to the nose of the target user. The scent ball is sufficiently small so that the olfactory experience is localized. In a project called "Scents of Space" by Hague Design and Research, a room was built to control the flow of the scent volume to travel in a uniform direction [6]. One wall was equipped with multiple boxes that shoot out the scent volume. By controlling which scent to release into the room, the room could be filled with different scents.

Taste has been the less explored area for entertainment computing. We all agree that eating is a form of entertaining experience, but controlling the gustatory experience with computers is difficult. Hashimoto et al. [7] have realized the virtual experience of drinking using a straw by controlling its air pressure.

In the following sections, two projects are used to show how sensuous media can be designed for entertainment computing.

10.4.1 Nozoki-Hana

Nozoki-Hana (Fig. 10.6) ("Peepin Nose in" in Japanese) is an entertainment of listening to scents and enjoying the imagination, with a background paying attention on the expressions of the five senses. The user experiences with headphones, actively places ones nose inside a hole, and enjoys the changes of scent and sound. The visual information is not used so that the user can experience the content with other senses.

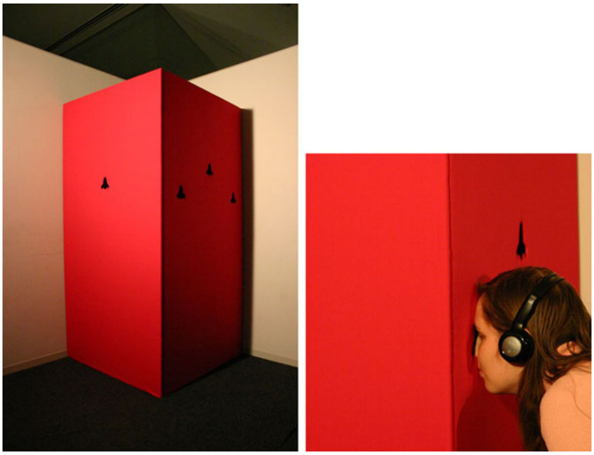

Fig. 10.6 Nozoki-Hana

10.4.1.1 Interaction Design

Nozoki-Hana offers scents based on the power to revive memory. Nostalgic scents and sounds that support the imagination for Japanese people are being placed in the four holes (e.g., the scent of curry and the sound of an elementary school class room). By discerning the four scents, the player experiences the reviving memories, and appreciates the new expression of "listening to scents."

10.4.1.2 Technology

Nozoki-Hana is a wall that contains nose-shaped holes. In each of these holes, a distance measure sensor and an original scent emerging device are planted inside a box. The scent emerging device is a cartridge filled with scents that uses a solenoid for opening and closing the valve. This enables producing a scent at a degree that prevents it from leaking outside the hole.

A distance measure sensor perceives the nose of a player when placed inside a hole, and sends the data to Transmission. Transmission is new software developed in Max/MSP/Jitter. Transmission functions in two ways by receiving the data. One of the functions is to move the solenoid of a hole where the nose of a player is being placed, controlling the discharge of scent and providing it to the player. The other is to mix and output the appropriate sound replacing the environmental sound. A mixed sound is delivered to the player's ear through wireless headphones. With this function, the player can enjoy changes in scent and sound, as if tuning a radio.

Fig. 10.7 Mamagoto

10.4.2 Mamagoto

Mamagoto (Fig. 10.7) is an interactive and context-aware dining system which encourages small children to "play" with food and offers entertaining dining experiences. For children, tremendous varieties of colors, textures, tastes, shapes of food and of dishes and silverware are full of amusement. Even when they seem to be messing up everything on the table, they are fully using their senses for new exploration, and this process of "playing" is important for the development of their senses.

10.4.2.1 Interaction Design

Mamagoto achieves sensuous interaction design with food using three focuses: texture, shape, and mixing interaction. Food has rich varieties of textures. Mamagoto provides an experimental application which exaggerates the texture of a pudding, and displays it as interactive animations on the tabletop. For shape, it is interesting to see varieties of shapes of food, and that those shapes constantly change by while eating. Mamagoto can capture shapes of food, and display them as animations. Mixing is one of the simplest methods of combining different foods. It blends colors, flavors, and it is a very entertaining action.

10.4.2.2 Technology

Mamagoto consists of a table and several small devices in forms of dishes and silverware. The tabletop is made of acrylic, and made translucent to enable projection of interactive animations as well as to capture the position of the dishes and silverware with a USB camera. In addition, a webcam is integrated in the table to capture faces of users, used for interactive feedback. Their actions are captured with different sensors integrated in dishes and silverware. Mamagoto has several applications to let small children "play" and interact with food using their natural gestures.

To implement the texture interaction, a touch sensor is integrated in the plate, and because puddings are electrically conductive, the pudding and the dish as a whole becomes a touch sensor. For shape detection, a USB camera captures the shape of the food and displays the shape on the table as an interactive animation. For the mixing interaction, Mamagoto has a spoon device which senses the mixing action, and the animation at the center of the table is "mixed" as users use the spoon. Mixing action is sensed by an accelerometer on the spoon.

10.5 Collective Media

The computer network has connected many individuals in remote locations as a social media. This social media serves as a platform for gathering to exchange information and ideas, as well as a place to get acquainted and develop intimate relationship. In addition, it allows creative people to collaborate for entertainment. Musicians and film makers are adopting this technology for online collaboration.

Collective creativity is a creative activity that emerges from the collaboration and contribution of many individuals so that new forms of expressive art and entertainment are produced collectively by individuals connected by the network. It is similar to Wikipedia and other collaborative online activities where each participant contributes to the whole. The collective power can be adopted for creative activity and the process itself becomes entertaining.

In the following section, we review our research project on Collective Creativity called Mopie.

10.5.1 Mopie

Mopie is an example of content that shows the strength of collective creativity. Mopie is a database-driven content to experience the city walking by simply tracing the street on the map that triggers to playback the video clip of the street walking captured by the user. Each user can contribute to this video database by capturing the video using video-enabled cell phones with a GPS unit when walking on the street. The database accumulates video clips contributed by multiple users. Mopie resembles Aspen Moviemap, a project at MIT in the 1970s, but it differs in how the videos are collected [13]. MIT researchers had to capture all the video footage by themselves, whereas Mopie relies on the individual contributions.

10.5.1.1 Interaction Design

The cell phone captures both the video clip of the street scenery and the location data, and these data are sent and archived in the database. To experience the street walking using Mopie, each video clip can be mapped onto the street map. People can have a virtual city walking experience by tracing the street map with a finger or a mouse. The video clip of the selected street is searched from the database and played. If multiple video clips are needed to continue walking, the system automatically loads appropriate clips and seamlessly plays the clip. The video clips archived in the database are contributions by many individuals, at different time and season. Collectively, the virtual city walking experience in Mopie becomes rich and memorable.

Fig. 10.8 Mopie

10.5.1.2 Technology

Mopie (Fig. 10.8) uses the camera and the GPS system embedded in a mobile phone to capture the street walking experience as video clips. GPS information is tagged to each video clip to automatically map onto the street map. The video and location data taken by the mobile phone is uploaded to a server, then the location data is formatted to xml, and the video data is formatted as an image sequence. When the user traces the street with a finger or a mouse, the video clip will be searched from the database using the GPS location metadata.

10.6 Conclusion

This chapter presented how everyday artifacts can be designed for entertaining experience using embodied interaction and the design for the five senses. In addition, we have shown an emerging area of entertainment computing research that uses the creativity of many individuals. In all the projects shown, designing for interaction and advancing the technology are equally important.

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Chapter 11
Tabletop Games: Platforms, Experimental Games and Design Recommendations

Michael Haller, Clifton Forlines, Christina Koeffel, Jakob Leitner, and Chia Shen

11.1 Introduction

While the last decade has seen massive improvements in not only the rendering quality, but also the overall performance of console and desktop video games, these improvements have not necessarily led to a greater population of video game players. In addition to continuing these improvements, the video game industry is also constantly searching for new ways to convert non-players into dedicated gamers. The recent success of Nintendo's Wii controller is often credited to its support of natural and intuitive gestural interactions, and much of the attention to this platform has come from its ability to attract people from markets not typically thought of as gamers. Indeed, stay-at-home parents, retirement homes, and working professionals make up a large portion of the Wii audience, which at the time of this writing is over 13 million (status Sept. 2007).

In addition to the popularity of gestural interaction, the multi-player nature of console games makes them more communicative than single-player desktop games. Even when desktop games are played in a multi-player mode, individual players are still separated from one another in front of their personal displays (see Fig. 11.1, *left*). Despite the growing popularity of computer-based video games, people still love to play traditional board games, such as Risk, Monopoly, and Trivial Pursuit. Monopoly, for example, has been sold over 250 million times[1] worldwide. Board games bring groups of people together around a table, and foster face-to-face communication in a social setting (Fig. 11.1, *right*). While engaging, traditional board games lack the interactive, graphical feedback provided by video games. Additionally, a single console is capable of playing a multitude of different video games, a feat that is obviously not possible for traditional board games because of their physical nature.

M. Haller (✉)
Media Interaction Lab, Hagenberg, Austria

[1] http://www.playmo-portal.com/spielzeug/Monopoly-in-Zahlen.html.

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Fig. 11.1 (*left*) Desktop-based games are often an isolated activity – even when gamers play in a multi-player mode. Therefore, traditional board games are still very popular (*right*)

Both video and board games have their strengths and weaknesses, and an intriguing conclusion is to merge both worlds. We believe that a tabletop form-factor provides an ideal interface for digital board games. In contrast to desktop based video games, tabletop gamers have the advantage of arranging themselves face-to-face while playing. This arrangement should lead to better collaboration and ultimately more enjoyment during the game. Several attempts have been made to bridge the gap between traditional board games and computer games [3], and there is evidence that tabletop-based video games merge some of the advantages of traditional board games and video games [1]. They combine the social interaction and the physical activity of board games with the visual, acoustic and haptic possibilities of video games [6]. Players are able to deduct other players' intentions by observing their actions [17]. The technical enhancements of the game board allow tasks that are perceived as cumbersome to the players (such as shuffling cards or counting the points) to be taken over by the computer. Thus, the player is able to fully concentrate on the game itself (e.g., strategies). Another advantage taken from video games is the capability to save the status of the game and resume it later.

The design and implementation of tabletop games will be influenced by the hardware platforms, form factors, sensing technologies, as well as input techniques and devices that are available and chosen. This chapter is divided into three major sections. In the first section, we describe the most recent tabletop hardware technologies that have been used by tabletop researchers and practitioners. In the second section, we discuss a set of experimental tabletop games. The third section presents ten evaluation heuristics for tabletop game design.

11.2 Tabletop Hardware & the Types of Interaction They Support

Multimodal interfaces that combine gestures with additional modalities such as speech have been examined since the early 1980s and have shown significant potential to make human–computer interaction in games more natural and efficient.

A number of systems have emerged in recent years in which we can interact by speech combined with pointing or more complex gestures. Using a variety of available sensors and targeting diverse use environments, existing research has addressed the recognition of detailed hand gestures as well as full body (pose) gestures [9]. Physical user action as an interaction modality have been recently explored in research projects, mostly in an entertainment/sports context and has entered the commercial realm with the EyeToys extension for the Sony Playstation 2 and with the Nintendo Wii console.

This section aims to identify several of the major tabletop hardware platforms that tabletop game developers might choose to target. Rather than provide a detailed explanation of each of the technologies, we aim to give the reader a brief overview and pointers to where they might find more information to aid them in their platform choice.

11.2.1 SmartBoard

SMART Technologies[2] has been selling interactive whiteboards since the early 1990s. While their main products have been and continue to be vertically oriented, touch-sensitive displays sold to the education, defense, and business meeting-room markets, researchers inside and outside the company have been experimenting with the horizontal orientation of SMART's products for several years.

The main sensing mechanism used in these whiteboards is a computer vision-based technology called DVit. Cameras placed in each of the four corners of the surface view a shallow region in front of the display. When a finger or stylus enters this region, the system calculates its position by triangulating the images of the finger or stylus from several of these cameras. Multiple cameras provide some redundancy in positioning; however, problems can arise as each touch effectively hides the parts of the display that are behind the touch as seen by any one camera. Similarly, objects placed on the table hide areas of the table from the view of the cameras and can interfere with the interaction. Four cameras (one in each corner of the display) seem to be enough to robustly support two points of contacts.

11.2.2 DiamondTouch

The DiamondTouch[3] table was first presented in 2001 by Mitsubishi Electric Research Laboratories as a multi-user, debris tolerant touch technology. Since then, it has become commercially available to researchers and application developers as

[2] http://www.smarttech.com.

[3] http://www.merl.com/projects/DiamondTouch/.

Fig. 11.2 Touches from different users on a DiamondTouch table are distinguished from one another through separate signals broadcast through each user's chair and capacitively coupled through the user into the table's antennas. The table distinguished multiple touches from different users

a research prototype and dozens of colleges and universities have received DiamondTouch tables through an educational loaner program. The sensing technology behind DiamondTouch is an XY pair of antenna arrays embedded in the surface of the table. Each user sits in a wired chair that broadcasts a unique radio signal. These signals are capacitively coupled through the user's body and into the antenna array whenever touches occur (Fig. 11.2). Because each user sits in a different chair, the table is able to distinguish touches among the users. Current prototypes support up to four users.

While objects placed on the DiamondTouch table do not interfere with input, problems can arise with multiple points of contact made by the same user as touches effectively mask other touches in the X and Y direction. In some situations, there is an ambiguity among multiple touch points, which has prompted many developers to rely on the touch's bounding box as the unit of input.

11.2.3 SmartSkin

SmartSkin was first presented in 2002 by Jun Rekimoto from the Sony Computer Science Laboratory. SmartSkin embeds a 2D antenna array into a surface, and supports multi-point, free-hand touch input. The technology works through sequentially using each antenna in the array as a transmitter while the remaining sensors are used as receivers. A users or users' arms and hands act to capacitively couple this signal from the single transmitter to every receiver in range, giving the system a picture of the areas of contact on the table. The capacitive sensors measure a range of values; thus SmartSkin can be tuned to not only sense contact with the table, but also hovering above it. Like DiamondTouch, SmartSkin is debris tolerant as non-conductive objects do not interfere with input. Similarly, SmartSkin does not rely on computer vision, making the technology resistant to changes in lighting and occlusion problems.

Fig. 11.3 All pictures are sent to the table's surface, once the WiFi-based camera is put on the table

11.2.4 Microsoft Surface

More recently, Microsoft presented the Surface table. This is expected to come to market later in 2008, but its price will initially limit its wider appeal. The system enables interaction with digital content through natural gestures, touches and physical objects. The Surface can track up to 40 simultaneous touches. In contrast to the DiamondTouch, the Surface is based on an optical tracking set-up, where five embedded infra-red cameras track the entire table (the current prototypes have a screen size of 30 inches). A special rear-projection surface and an embedded projector allow an optimal image. With the special projector, the engineers developed a relative low-sized table with a maximum height of 56 cm. The Microsoft team demonstrates the table's advantages with effective demonstrations developed for Sheraton Hotels, Harrah's Casinos, and T-Mobile. In the photo-sharing application, for instance, friends can put their WiFi digital camera on the table and share their photos in a very natural way (see Fig. 11.3).

An alternative is to recognize and pair a device with RFID (Radio-Frequency Identification) tags or NFC (Near Field Communication). In this case, the table includes RFID readers which in combination with RFID tagged objects can be used to save and load different content. NFC allows devices to set up a link when brought together in close proximity. It is primarily designed to be used on mobile phones. The content, however, has still to be sent over Bluetooth (or another suitable link), since the NFC technology is not designed to transfer large amounts of data. RFID/NFC is likely to be included in increasing numbers of mobile phones and other devices, so in the future it may be possible for a user to have content from a mobile device appear on a large screen just by bringing their device within close range of the display.

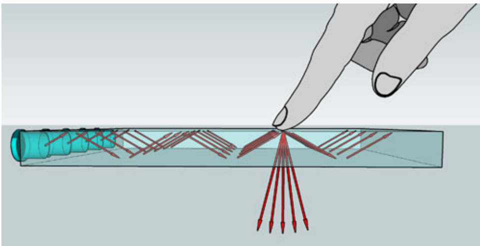

Fig. 11.4 Light that enters the acrylic table reflects internally until it is scattered by the finger-acrylic surface on the display. The light is then reflected downward, through the display to where it is seen by a camera

11.2.5 Frustrated Total Internal Reflection (FTIR)

While FTIR is a long and well known physical phenomenon and has been used for many years to capture fingerprint images in the biometrics community, it has recently gained much popularity in the tabletop research community in large part because of the 2005 work of New York University's Jeff Han [8]. FTIR works through exploiting the physical property of the total internal reflection of light traveling through a medium such as glass or acrylic. Light that enters the side of such a sheet tends to reflect internally and remain inside the sheet. Fingers or other objects that touch the surface "frustrate" this reflection and scatter light away from the glass (Fig. 11.4). When the glass sheet is observed from the side opposite the user, touches appear as bright spots that are easily detected with a computer camera. Han describes the use of IR light paired with an IR-sensitive camera, which makes the input technique compatible with rear-projection displays. The relatively low cost of this input solution paired with the freely available libraries[4] for performing the computer vision necessary for input has made FTIR a popular input choice for tabletop researchers.

11.2.6 Entertaible

Philips announced the interactive Entertaible in early 2006, and quickly began demonstrating multi-user tabletop games. While not yet commercially available at the time of this writing, the Entertaible combines a 30″ LCD screen with multi-point touch detection to provide a multi-user entertainment device for group game playing. Philips has announced that their first market will be restaurants, bars, and casinos; however, they plan to eventually target the home market as well. Sensing input is performed with a series of LEDs and photodiodes that are arranged around the perimeter of the LCD screen. Objects placed on the table, as well as users' hands and fingers, block the view of the LEDs by the photodiodes on the opposite edge of the table. Using this occlusion technique, Philips has demonstrated the simultaneous detection of dozens of finger-sized objects.

[4]http://code.google.com/p/touchlib/.

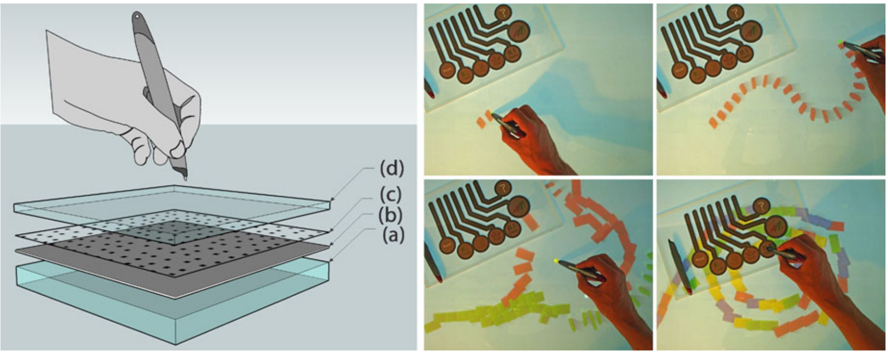

Fig. 11.5 (**a**) The rear-projection table has tiny dots printed on a special foil. (**b**–**d**) The different layers of our trackable table. In the game Comino, digital domino pieces can be placed with a digital pen

11.2.7 Stylus

Another way to interact with a table can be done by using a stylus. Figure 11.5 depicts a solution of a rear-projection table in combination with a stylus. To capture the users' movements on the table, we use the Anoto pen.[5] Anoto-based digital pens are ballpoint-pens with an embedded (IR) infrared camera that tracks the pen movements simultaneously. The pen has to be used on a specially printed paper with a pattern of small dots with a nominal spacing of 0.3 mm. Once the user touches the pattern with the pen, the camera tracks the underlying pattern. It can then derive its absolute coordinates on the pattern and send them to a computer over Bluetooth at a rate of 70 Hz. Anoto pens with Bluetooth are available from Nokia (SU-1B), Logitech (io-2), and Hitachi Maxell (PenIT). From the pen, we receive the pen ID, the ID of the pattern sheet (each page has a unique pattern), and the position of the pen tip on the paper.

The digital pen (a) tracks the pattern, printed on a special Backlit foil (d), which generates a diffuse light. Thus, no spotlights from the projectors are visible at the front of the screen. Moreover, the rendering and the brightness of the projected image are still of high quality. In our setup, we used one A0 sized pattern sheet (118.0 × 84.1 cm). The pattern is printed with the black ink cartridge (which is not IR transparent and therefore visible for the IR camera). Notice that the colors Cyan, Magenta, and Yellow (even composed) are invisible for the IR camera. The pattern is clamped in-between two acrylic panels (b) and (c). The panel in the back has a width of 6 mm and guarantees a stable and robust surface, while the panel in the front has a width of only 0.8 mm to protect the pattern from scratches. We noticed that the acrylic cover in the front does not diffract the pattern at all. However, using thicker front panels (e.g., 4 mm), produces bad tracking results. While we also successfully

[5] http://www.anoto.com.

tested our tracking with a transparent foil, we did not achieve good tracking results using the pattern foil in front of a plasma or an LCD display.

11.3 Experimental Tabletop Games

In terms of a game's interaction style, there are many dimensions with which one can classify and describe tabletop games. We can consider a game as either *collaborative* or *competitive* to describe the presence or absence of competition among players. Similarly, players may act as part of a *team* or as an *individual*. The pacing of tabletop games is typically *turn-based* or *live-action*, describing whether or not input is performed concurrently by multiple players, or if players take turns. Finally, games might be classified as either *strategy* or "*twitch*" games to describe the relative importance of planning game commands vs. executing them.

In reality, a game will most likely embody more than one of these classified dimensions, or even switch between classifications during different parts of the game play, thus making pigeonholing a particular game difficult. Game designers usually use certain genres as they explore the design space to arrive at the goals of the game. Digital tabletop games are emerging internationally as both research projects and commercial efforts. A selective set of contemporary work is reviewed in this chapter. This set is not meant to be exhaustive, rather the intention is to provide a variety of genres for the readers to explore. In this section, we use a broad categorization of games: *educational, therapeutic*, and *entertainment*.

11.3.1 Educational

In recent years, researchers at universities and in research labs have started to build tabletop games for educational purposes. PoetryTable, Habitat, a language (Spanish and English) learning table are some of the examples in this category (see Fig. 11.6).

PoetryTable [16] is an educational game, inspired by the popular "magnetic poetry" toy.[6] The PoetryTable allows students to create free-form sentences and phrases by moving word tiles around the table with their fingers. Working individually or collaboratively, up to four users work to create poems in either English or Japanese. Popup menus give users the option to make duplicates of popular word tiles, to add a suffix or prefix to a particular word, to conjugate verbs, and to save a screenshot of the game in order to preserve their poems. The activity is made more challenging by presenting both correct and incorrect options for students to choose from in the conjugation menus.

[6] http://www.magneticpoetry.com.

Fig. 11.6 The PoetryTable allows students to create free-form sentences using current vocabulary words. Double-tapping a word tile invokes a menu that allows the student to alter the word by adding prefixes and suffixes

Implemented using the DiamondSpin Toolkit [16] and running on a DiamondTouch table, this tabletop game has been a fixture at the reception area at the Mitsubishi Electric Research Labs for three years. Some of the observations and experience from this game have been reported in [15].

Habitat is an educational game also implemented with the DiamondSpin Toolkit. The gametable is divided into five distinctive areas (cf. Fig. 11.7). The center area is a large diamond which reads "*help the animals get home*." When the game starts, this region is filled with a set of animal images. The four large corner areas are "home environments" labeled as *land, placeForest, sea, and ice floes*. Each of these four corner areas has a back ground image representing the typical home environment for species of animals according to the text labels. Players work together to match animals with their home environments by dragging the animal images to the correct regions of the table. When a correct match is made, the player is rewarded with a sound that reflects some quality of the animal (e.g., the cry of a wolf). When the match is incorrect, the animal snaps back into the center of the table and an error sound in played. Organized by *WIRED* magazine, the three-day NextFest 2004 was designed to give the general public a close-up, hands-on view of innovative technology. The game Habitat was run at this conference as one of the applications on a DiamondTouch table, which was part of the Future of Design Pavilion. During the course of this event, the tables were used by almost 2,000 people. Visitors included children, educators, executives, designers, and engineers. It was observed that children (aged 2 to teens) needed no tutoring or coaching in playing the Habitat at all. Most of the children simply approached the Habitat table and immediately started

Fig. 11.7 The Habitat allows multiple people match images of animals to their home environments

to move the animal images to the corner regions. More than on child sometimes wanted to "grab" the same animal image. Fortunately, a double-tap invoked menu allowed images to be duplicated on the spot. We observed that some adults had more hesitations without coaching. In particular, some adults were not sure what to do when a beep was heard and the animal image "jumped" back to the center after they had dragged it to an incorrect home environment.

The ClassificationTable [13] game begins with a pile of virtual "clues" placed in the middle of the table. "Clues" are sentences, phrases, or single words that are related to the current lesson. Each corner of the table is labeled with one of four categories for the lesson, and the players work together to classify each of the clues into one of these categories. Example categories include countries, characters from a novel, authors, vocabulary themes, number of syllables, and so on. Players receive feedback for both correct and incorrect classifications, and at the end of a session, the students view a histogram showing the relative contribution from each member of the team.

11.3.2 Therapeutic

Researchers [7, 13] have also explored how interactive table technologies, specifically cooperative tabletop computer games, can help mental health therapists facilitate adolescent and children's social skills development in a comfortable and motivating way. Tabletop technology encourages face-to-face interaction around one

Fig. 11.8 (*left*) SIDES is a turn-taking game. (*right*) A screenshot of StoryTable which uses multi-user collaborative gestures to help children with High Functioning Autism to work together

computer in a way other computer workstations and video gaming systems do not. Adolescents with Asperger's Syndrome (AS) often describe the computer as a comfortable and motivating medium.

SIDES [13] is a four-player cooperative computer game for social group therapy on the DiamondTouch table (see Fig. 11.8). It was developed at Stanford University as an experiment for therapists in working with Asperger's Syndrome children. Utilizing the multi-user identification feature of the DiamondTouch platform, the designers of SIDES built in game rules to require and/or restrict input from certain players. This affordance forced the children to cooperate during the game. SIDES is a highly visual, four-player puzzle game. The game rules were designed to increase collaboration and decrease competition. At the beginning of a round, each player receives nine square tiles with arrows (three copies each of three arrow types). Unique arrow types (e.g., pointing left, pointing right, around-the-corner, etc.) are distributed among participants so that no participant has all 12 arrow types in his "hand." Students are asked to work together to build a path with their pieces to allow a "frog" to travel from the start lily pad to the finish lily pad. There is a limited supply of each arrow type, thus encouraging students to cooperatively build an optimal path to win the most points. To gain points, the path must intersect with insect game pieces on the board. The insects are worth various point values (e.g., each dragonfly is worth 20 points). The group of students must agree on one path that collects the most points with their given amount of resources. Once all players agree with the solution, the frog will travel along the path and collect points by eating all the insects it encounters. Each player has a control panel in the region of the interface closest to his or her chair. In each player's control panel, there are round and point indicators as well as voting buttons to test a path, reset, or quit the game. The voting buttons force the group to "vote" unanimously in order to change the state of the game. For instance, players must vote unanimously to test their path once a solution is reached by each activating their own "Test Path" button. This feature was implemented to ensure that no one player had more control over the state of the game than another player, and to encourage social interaction by necessitating communication and coordination with other members of the group.

The control panel includes a turn taking button. Each player's turn taking button indicates whether or not it is that player's turn. A player may make as many moves with his own pieces during his turn as he likes. The player whose turn it is has control over when he ends his turn by pressing his turn taking button. This is a "give" protocol as described in order to prevent one student from "stealing" control from another player.

A version of the StoryTable interface [7] was developed jointly by University of Haifa, Israel and ITC-irst, Italy. The game was designed according to the concept of ladybugs wandering around the table surface. The game is developed on the multi-user multi-touch DiamondTouch tabletop. Ladybugs were chosen as a familiar, friendly object to children; the users had no difficulty in understanding the function of the ladybugs that differed in size and color in accordance with their functions. A mixture of standard touch events and the new multi-user events were used as a means to control the objects. One ladybug carries the backgrounds, the context within which the story will be set, e.g., a forest, a medieval castle, etc. This ladybug can be opened to access the backgrounds by double touching on it. Since the selection of the background is crucial for determining the story, the system forces previous agreement by requiring that selection of the background setting be done jointly by the children, i.e., through a multi-user touch event. Another ladybug carries the various story elements (e.g., the Princess, the Knight) that can be dragged onto the current background. Again, this ladybug can be opened by a single-user double touch event. In this case, however, the elements can be dragged autonomously by each child. A third type of ladybug of a different size and shape (the blue ones shown in Fig. 11.8 (right)) contain the audio snippets that will form the story. In order to load an audio snippet into one of these ladybugs, a child has to drag it into the recorder and then keep the button pressed while speaking. The audio snippets are recorded independently by each child. Once loaded with audio, the ladybug displays a colored aura that represents the child who recorded it. An audio ladybug can be modified by the child who recorded it, but the system refuses modifications attempted by other children. Therefore, a ladybug is "owned" by the child who recorded it. Yet, children may agree to release ownership of a ladybug by a multi-user drag-and-drop action: if they jointly drag the ladybug onto the recording tool, the system removes the content and the aura. The resulting story is the sequence of the audio snippets recorded in the ladybugs placed in the sequence of holes at the bottom edge of the interface; while each audio ladybug may be listened to individually, the story as a connected sequence of snippets can be listened only if children touch the first ladybug in the sequence. Baumingger et al. reported an experimental study on 35 dyads. They provided evidence that this setting facilitates more complex and mature language (both in their recorded story segments and in their interactions with one another during the task) and that the contributions to the story and to interaction were more equally distributed between the children in the StoryTable than in the control condition.

11.3.3 Entertainment

In order to improve the social gaming experience, Magerkurth et al. proposed a tabletop setup which combines the advantages of a digital environment with the social impact of board games [11]. The game combines a wall and a digital display. Users play with their personal devices and with the public displays, and the communication can be done through headsets (for personal communication) and loudspeakers (public communication). Moreover, users are sitting face-to-face, they share the same experience, and they play in a new digital/real world. Most of recent work on interactive surfaces deals with merging real with the virtual (digital) enabling people to share the same experience.

Barakonyi et al. present in [2] the game MonkeyBridge and extend the idea of Magerkurth. They implemented a collaborative Augmented Reality game employing autonomous animated agents. Although playing around a table, the authors implemented their game using HMDs. Again users can use real objects, which have to be placed correctly, to guide digital, augmented avatars.

Wilson demonstrated PlayAnywhere, a flexible and transportable tabletop projection setup [18] and PlayTogether, an interactive tabletop system that enables multiple remotely and co-located players to engage in games with physical games pieces [20]. Wilson also presented the pairing of a depth-sensing camera with an interactive tabletop to create a car racing game in which virtual cars raced realistically over physical objects placed on the table's surface [19].

KnightMage is based on the STARS-platform [11] and is played collaboratively by multiple users sitting around the STARS-table. The players have to survive together in an inhospitable environment, relying on each other's special abilities to face a different task in the game. In special situations, the players can also act as lone warriors to collect treasures which are hidden from the other players. These private interactions are performed through a handheld device that allows each player to access the inventory and special abilities of his own game character. The hardware setup of KnightMage consists of a tabletop display and a wall display, on which participants can share relevant information to other players. All the hardware components are part of the STARS platform, and were originally developed as part of the Roomware project. The STARS platform is designed to support classical board games with the use of various multimedia devices. With the use of several displays which can either be public or private displays, the STARS setup allows developers to create very complex game scenarios which can, for example, be both collaborative and competitive elements in one game. Setup components include a touch sensitive plasma display which acts as the game board and which is coupled with a camera capturing the setup from the top. The camera allows the system to detect and identify game pawn on the interactive screen. In addition, the table includes RFID readers which in combination with RFID tagged objects can be used to save and load different scenarios and games. The STARS system also puts a strong focus on providing audio channels to communicate with the users of the system. Both public messages via loudspeakers and private messages via earphones are can be delivered by the system.

Weathergods [1] is a turn-based game that can be played by up to four players simultaneously on the Entertaible system. Each player has three different pawns that can perform different actions in the game. The goal of the game is to earn enough gold to be able to buy oblations to please the weather gods. Gold can either be earned by selling camel milk, robbing other players or detecting gold in the soil. The virtual game environment helps the players learn the game's commands by displaying possible pawn movements and reacting to the action of the players. Special attention was paid to the very iconic style of the pawns, which are tracked by the tabletop surface. The pawns that are placed on the screen are manufactured from a translucent material which transports the light to the top of the pawn based on total inner reflection. This way, by changing the underlying pixels on the screen, the color of the pawn can be changed.

11.4 Case Studies

11.4.1 Jam-O-World: CircleMaze

The goal of the Jam-O-World project was to encourage people to come together to take part in a collaborative musical gaming experience in an immersive 3D environment. The Jam-O-World game play environment includes a modified Jam-O-Drum (originally developed at Interval Research [4]), which is an interactive tabletop display with reactive MIDI drum pads embedded in its surface. The project is the creation of a team of graduate students and faculty from the Entertainment Technology Center at Carnegie Mellon University, who set out to augment the Jam-O-Drum with new input modalities and create a set of musically enhanced games. The tabletop form factor of the Jam-O-Drum is particularly appropriate for the goals of this project as it arranges players in a circular formation, allowing them to see and interact with one another around the table. Tabletop games written for Jam-O-World are controlled through interaction with the embedded drum pads as well as interaction with a "lazy-susan" like dial at each of four player stations. Interaction with these two input devices controls the visual and aural facets of the games. Engagement is further enhanced by projecting computer graphics not only on the tabletop itself, but also on the walls and ceiling of the surrounding environment.

Jam-O-World games are designed to require physical and social interaction, as well as either collaboration or competition among players. Because Jam-O-World was originally built for a museum exhibit, two major design goals were to facilitate walk-up-and-play ease of learning and encourage interaction among players who may not know one another. In the following sections, we describe the design of one game in detail. Readers interested in learning about some of the many tabletop games written for the Jam-O-World platform should visit the project website.[7]

[7] http://www.jamodrum.net/.

Fig. 11.9 In CircleMaze, players work together to align pathways through four concentric rings. CircleMaze has been presented as part of several museum exhibits

11.4.2 CircleMaze

The CircleMaze game was one of the early games designed for the Jam-O-World environment. In this game, players work together to control four concentric circular rings projected on the table. Each one of the four color-coded lazy-susan turntables around the edge of the table controls one of these rings in a direct manner. Players must collaborate to rotate these rings in such a way that the rings' pathways align to allow virtual balls to travel from the outside edge of the table into the center of this concentric maze (see Fig. 11.9). A central clock counts down the seconds remaining, and teams gain extra time for each ball that reaches the middle. If the clock expires, the team regresses one level and if all the balls reach the middle of the maze, the players advance to a more difficult level. Players quickly learn that success is impossible without communication and collaboration among players as it is not possible for any one player to align all of the pathways necessary to allow the balls to reach the center of the table.

While playing the game, the rotation of each of the four rings controls the mixing of four recombinant tracks of music – percussion, base, melody, and vocals. Through playing the game and turning the rings, the players create a changing mix of cohesive music that follows their actions. While this music making is secondary to the main goals of the game, it does provide players with a non-repetitive background track which is appreciated by museum staff.

11.4.3 User Testing and Observations

Early testing of CircleMaze showed that players had difficultly grasping the rules of the game and their role in the collaborative effort when they first approached the table. To counter this difficulty, we designed a simple first level of the game which included one path on each ring and only one ball. Because players come and go in a museum environment, the game was designed to regress to this early level if teams were having difficulty playing the game.

Another early observation was that when left running, the table did little to attract new players when not in use. When the game is in full swing, graphical animations and dance music kept some new players from approaching the table. To better attract players and teach novice players the reactive areas of the table, CircleMaze enters an attraction mode when it has been idle for several minutes. In this mode, music plays quietly while the only graphics projected on the table serves to highlight the disk and drum pad controls so that museum visitors are attracted to touch these areas of the table and start a new game.

11.4.4 Porting to a Direct-Touch Tabletop

Several months after the initial museum installation of CircleMaze, one of the authors ported the tabletop game to Mitsubishi Electric's DiamondTouch table. The new input device allowed for the direct under-the-finger manipulation of the rings in the game and removed the indirect input modality of the circular disks. One of the major goals of the game (the forcing of collaboration among players) seemed particularly appropriate for one of the distinguishing features of the DiamondTouch table, namely user identification. Touches from each player are distinguished from one another, and the game's rings only respond to touches from the ring's user. Again, successful completion of the game requires the collaboration and planning among all players.

11.4.5 Comino and NeonRacer

Comino and NeonRacer have been designed and developed at the Media Interaction Lab.[8] Both of these games are tabletop games, combining physical and digital content. Inspired by the Incredible Machine, the general objective of Comino is to allow players to arrange a given collection of digital and real objects in a desirable fashion to perform a simple task (e.g., to put a ball from one point to the exit). Each level presents a puzzle requiring multi-modal interaction provoking user creativity. In some levels, there are some fixed objects, which cannot be moved; therefore, the only way to solve the puzzle is to arrange carefully the given real and digital objects around the fixed objects. Using the wireless pen-interface, players can *draw* a path

[8] http://mi-lab.org/.

Fig. 11.10 (*left*) Players have to draw a path on the surface for placing digital domino tiles. (*right*) Different physical objects have to be used for pushing the real/digital domino pieces. The photo sensor of a tower, for instance, can track the falling physical piece and push the digital ones

on the table's surface for placing digital domino tiles (see Fig. 11.10). Moreover, users are also required to place *real* physical domino pieces on the table surface if the digital domino tiles have been consumed. Special physical objects, the so-called "portals," are used to connect the virtual world with the real world. Using these portals, the real domino bricks can be knocked over by the virtual ones and vice versa. In the setup, two portals have been used which were connected over USB with the computer.

Of course, multiple players can work simultaneously. While one person is placing the *digital* domino tiles, another player can start setting up *real* domino pieces directly on the surface. In some cases, players even have to switch between the two spaces (e.g., if they have to check that the real towers trigger the digital domino tiles). The first version of Comino included five levels which had to be solved by the players as fast as possible.

NeonRacer creates a rich gaming experience by using everyday objects in an unusual way. The physical objects act as the setting of a racing game for multiple players standing around the gaming table (see Fig. 11.11). The world is selectively augmented with the players' vehicles, which are controlled by traditional game pads. The racing course itself is defined by virtual checkpoints. Real, tangible objects placed on the course are detected by an infrared camera mounted inside the table and act as obstacles in the game. The position and edges of real objects are detected using the camera and a natural feature tracking approach. Thus, in order to hinder the other player's movements, users have to maneuver their vehicles past the real objects and through the checkpoints. Both players and spectators can move objects around the course. Passive bystanders can also actively contribute to the outcome of the race and even take sides, which again increases the social interaction and fun for players and spectators alike.

11.4.6 User Testing and Observations

Both Comino and NeonRacer have been designed to be used as an installation for a museum. In our initial pilot study, we tested 12 people (6 groups) from our local

Fig. 11.11 (*left*) Players have to control their digital cars on the tabletop interface. (*right*) Physical objects can be put as obstacles on the surface

university, who were not affiliated with the game design and development team. The overall participants' reaction was very positive. Users really liked the idea of playing with a tabletop interfaces that combined the real physical objects in a digitally augmented environment. Participants had the impression that they were playing within *one* space, transitioning between the physical and digital smoothly. While the interface of Comino was perceived as very intuitive, many players had problems with the game pads playing NeonRacer. Instead, they would prefer a more intuitive interface to control the digital cars. During our study, we observed that participants often had orientation difficulties while controlling the digital cars with the game pad.

In a first version of Comino, the physical towers were not implemented wirelessly. Players often had difficulties handling the cables. Interestingly, they never placed digital domino tiles close to the cables – even if they could have done so (cf. Fig. 11.12). In our current version, we have a Bluetooth version of the towers which is greatly preferred.

Another challenge was to find the optimal perspective for the 3D digital content, since in special cases (while looking to the scene with a really flat angle) players can have a distorted view of the scene.

11.4.7 Interaction Design for a Walk-up-and-Use Tabletop Game

Designing for a museum exhibit requires creating an interface that visitors can grasp quickly. Tabletop games are no exception. CircleMaze, for example, uses a simple consistent UI during all portions of the game, with players' actions always resulting in the same results. Players are not required to learn a series of actions and modes for the game's controls (as one sees in console or PC games, during which the player has a long-term engagement with the game and can invest a lot of time learning the game's controls). Players have only two options: turn the disk or hit the drum pad.

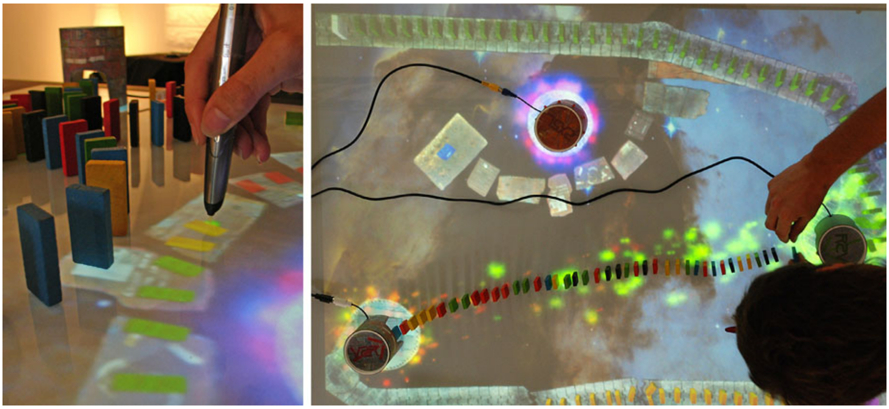

Fig. 11.12 (*left*) The cables of the physical towers were disturbing participants while placing the domino pieces. (*right*) In some cases, the perspective of the domino piece can become distorted

Visitors often spend about two hours in a museum. Usually, they are on the move to get a sense of the whole exhibitions and pausing casually at some installations. Actually, they only give time and attention to those installations they find particularly engaging. Therefore, it is essential that they understand quickly how to interact with the installation. In CircleMaze, novice players can quickly explore every possible action without help from another player or in-game persona, and these actions (and there results) quickly become second nature, allowing the player to focus on higher-level goals, advanced strategy, and social interaction. If the table only supports a stylus interaction, novice users often get confused because they expect to interact with the table by touching the surface with their fingers. In the next section, we are presenting eleven heuristics which are useful for everybody developing tabletop games.

11.5 Heuristics for Tabletop Games

The development of tabletop games is an iterative process throughout the development cycle, combining different usability evaluation methods such as heuristic evaluation, cognitive walkthrough and user testing.

We propose a heuristic evaluation already in the early phase of the design process. Heuristic evaluation is an expert based usability evaluation method, first introduced by Nielson et al. in 1990 [12]. In 2002, Melissa Federoff presented around 40 heuristics for video games where she tried to assess the applicability of Nielsen's heuristics to video games [5]. In the same way, Desurvire et al. released a new set of verified heuristics to evaluate the playability of games, the HEP (Heuristic Evaluation of Playability). As mentioned by the authors, their heuristics are helpful in early game design and they facilitate thinking about the design from the user's point of view.

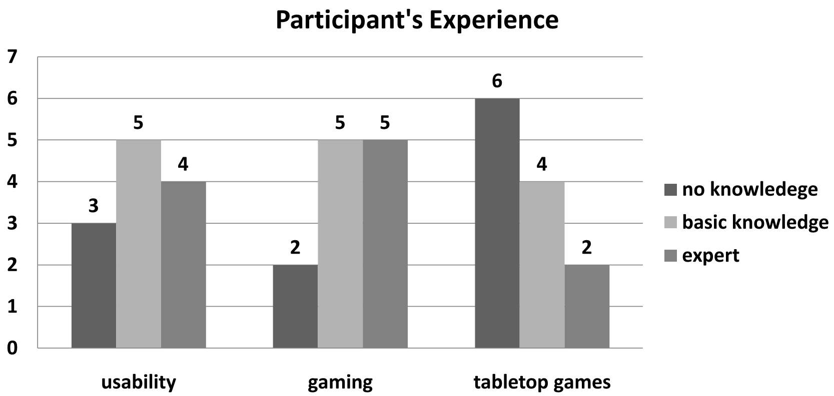

Fig. 11.13 The experience of the volunteers participating in the heuristic evaluation. Altogether four usability experts, five gamers and two experts in the field of tabletop gaming participated in the evaluation

Röcker et al. adapted HEP for pervasive games. The results of a study conducted by them have shown that the heuristics proposed for the game mechanics are the same for all types of games. The authors found out that it might be helpful to extend existing usability guidelines, as they are also related to interface elements, which might be fundamentally different in smart home environments (e.g., speech control, gesture recognition, or integrated and ambient interface elements might require adapted design guidelines). Further heuristics for the evaluation of video games have been developed by Nokia [10].

11.5.1 Evaluation Process

For the heuristic evaluation of tabletop games, we propose employing heuristics applicable to video games for the game play/game story and virtual interface related aspects. Nevertheless, the special properties of tabletop games are to be evaluated separately. Therefore, we iteratively developed ten heuristics targeting the special aspects of tabletop games. In total, we developed and reviewed four evolutionary sets of heuristics for tabletop games.

The first set of heuristics, including eleven heuristics, was developed according to existing research trials and could be described as important aspects in the development of tabletop games rather than as proper formulated heuristics. For the second set of heuristics, the heuristics have been re-phrased in order to be more appropriate and understandable. Furthermore, it has been formally proven against available literature on heuristic evaluations [14], and feedback from usability experts and experts in the field of tabletop gaming has been taken into consideration. The third set of heuristics has been developed based on the results of the review mentioned before and was tested through a formal heuristic evaluation. Twelve evaluators, aged

Fig. 11.14 The four evaluated games: (*upper left*) Casa Memo based on the DiamondTouch, (*upper right*) Comino, (*bottom left*) NeonRacer, and (*bottom right*) PenWars based on the interactive table of the Media Interaction Lab. Readers will find more information on the following website http://www.mi-lab.org/

between 22 years and 41 years (SD = 5.22) were asked to perform a heuristic evaluation of four tabletop games each. Two evaluators had no knowledge in the field of usability, five evaluators had basic to medium knowledge of usability and four could be considered as usability experts (cf. Fig. 11.13).

One evaluation session lasted between two and four hours depending on the number of times the evaluators played the games and the amount of feedback obtained. Since all games offered multi-player functionality, the evaluators were arranged in groups of two.

Four games have been evaluated (cf. Fig. 11.14). Besides Comino and NeonRacer, we also tested Casa Memo and PenWars. Casa Memo is a desktop-based memory game developed by ABC-Ware,[9] which was played on the DiamondTouch table. The overall goal of the game is to find pairs of cards as fast as possible by flipping over hidden cards. The flipping was realized by touching the card on the table. In contrast, PenWars is a real-time strategy tabletop game based on a stylus interface. Players can sketch tanks in order to compete against the opponent's units. All players have a certain amount of digital ink which affects the number of units

[9] http://www.abc-ware.com/.

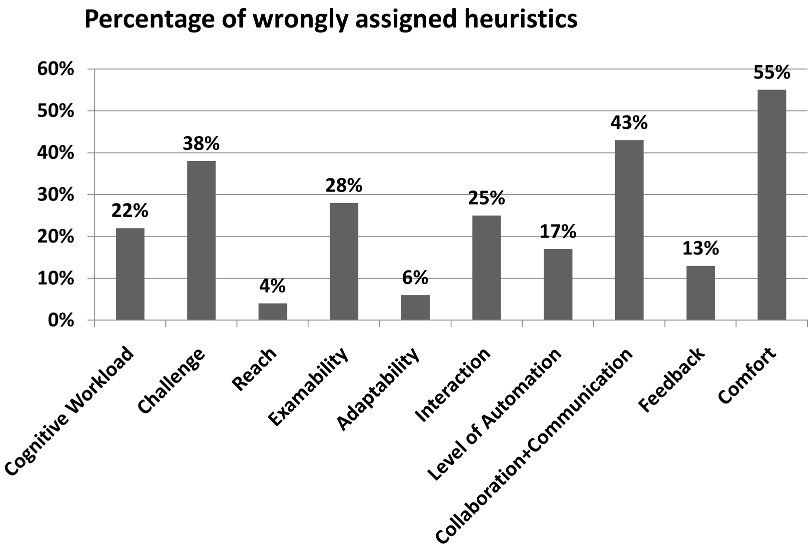

Fig. 11.15 The percentage of incorrectly assigned usability issues per heuristic

that can be created and their attributes. The tank's properties are represented in its size and shape. A large tank, for example, is stronger than a smaller one, but at the same time slower and less flexible in its movements. To win the game the player has to carefully consider the properties of the opponents' units, in connection with the map on which the game is played, when creating his own tank units.

At the beginning of the session, each participant obtained a paper explaining the proposed heuristics. The sequence of the games to be evaluated was counterbalanced so that learning effects or other influences would not affect the overall results. Each game was introduced separately to the participants. After playing the game, the participants had to examine the game again (up to six times) and verbalize encountered usability problems. Once finished examining the game, they were asked to categorize the usability problems they found into the proposed heuristics. At the end of each session, they were invited to check the heuristics for finding potential other problems that they might have overlooked before. During the heuristic evaluation 299 usability problems (138 classified problems) have been found (e.g., it is not possible to reach over the table playing Casa Memo). Since the quality of heuristics can be distinguished by the ease of assigning problems to them, the failure rate was an important indicator for their efficiency. The results obtained have shown that a total of 74 out of 299 heuristics have been assigned incorrectly, which is a failure rate of 25% (see Fig. 11.15).

For the final set of heuristics, the third set of heuristics containing eleven heuristics has been modified according to the results obtained throughout the formal heuristic evaluation. Most of the heuristics (especially those concerning comfort, collaboration, communication and challenge) have undergone drastic changes and in order to clarify the heuristics, sub-categories have been introduced.

11.6 Ten Heuristics for Tabletop Games

Summarizing, we identified ten heuristics which are essential for developing tabletop games. In the following sections, we describe them in more detail.

11.6.1 Cognitive Workload

The cognitive workload, which is not related to the game play (i.e., in connection with the acquisition of skills, the view, the screen orientation and the input methods), should be minimized.

The player's cognitive workload should be adapted to the game play so that the player is not overburdened in a way that the challenge of the game is negatively influenced. The learning curve should be kept short and unnecessary overexertion caused by display-connected issues, orientation, or input devices should be avoided.

11.6.2 Challenge

The system should be designed in a way that the challenge satisfies the preconditions of a tabletop setup and the target group.

The extended possibilities of tabletop setups should be used to design an appealing game play. Thus, the challenge should be defined by the tabletop setup. This also includes the challenge produced by input devices. Furthermore, collaborative and competitive tasks can provide additional challenge for a game.

11.6.3 Reach

The reach of the players should be adapted to the requirements of the game play.

Not every game requires the gamers to reach over the entire table. Participants can collaborate table-wide, not requiring a private workspace or they could need a certain private workspace in front of them (e.g., even mobile devices are a nice idea as proposed by Magerkurth [11]). The reach of each person is different depending on whether the person is sitting or standing. In our tests, we employed both types of setups. When players are required to share input devices, every player should have access to the device – even if they don't need it permanently, users should have the impression to have the same access to all devices.

11.6.4 Examinability

The players should not be hindered to examine the area required by the game play.

The examinability is the area of the tabletop surface, which the player is able to examine visually according to the game play. The virtual examinability allows the player the comprehension of information provided by the displayed interface and the real examinability can be understood as the player's possibility to see the displayed objects on the table surface without physical objects hindering the perception.

11.6.5 Adaptability

The system should be adaptable to the player in terms of the setup.

The tabletop systems/setup should have an ideal configuration for the players represented by the target group (e.g., allow the support for different seating positions during a game session, enable children as well as adults play the game on the same setup). On the other side, the game should be adaptable to other hardware configurations – it should be usable on a top-projection setup as well as on a rear-projection setup, and be playable while sitting or/and standing around the table.

11.6.6 Interaction

The interaction method should satisfy the expectations of the player and follow the game logic.

Most of the players have already more or less experience in gaming, and consequently some of them are familiar with different input devices. Therefore, the interfaces should conform to industry standards (e.g., from video games), if available, and be usable in a very natural, easy and understandable way [14]. The controls used in the setup should be intuitive, consistent, and meet the player's expectations. Furthermore, also the proportions of the game elements (real and virtual) should be kept realistic according to the game play.

11.6.7 Level of Automation

The player should be able to execute all actions relevant to the game himself/herself.

All actions that are perceived as boring, cumbersome and rather unimportant to the game should be performed by the computer. Nevertheless, the actions that are essential to the game play should be accomplished by the player [11].

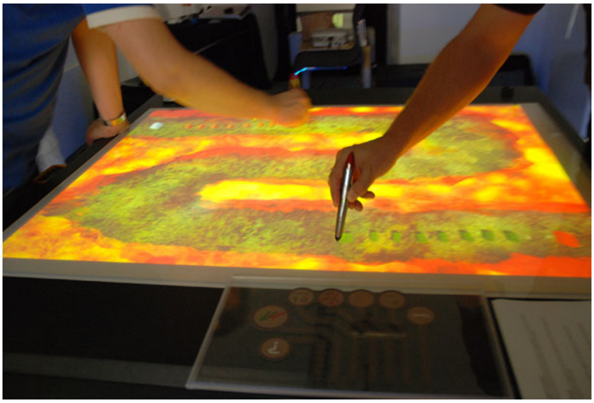

Fig. 11.16 The game play of Comino encourages close collaboration of the players

11.6.8 Collaboration and Communication

The interpersonal communication and collaboration should be supported by the entirety of the game (such as game play and setup).

The technology is not supposed to interfere with the collaboration; moreover, it should sufficiently support it. The game play should be designed to encourage collaboration or even competitiveness (see Fig. 11.16). The entirety of tabletop games (design, setup, game play) should aim at enhancing collaboration and communication between players. The game play should demand players to interact and talk with each other about different situations which might be either collaborative or competitive.

11.6.9 Feedback

Feedback and feedthrough should be adapted to the possibilities of tabletop games, used adequately, and be provided to the players when appropriate.

Feedback is meant for the person executing the current action and helps to understand what users have just done, and reassures them that they have done what they have intended to do. It can be purely visual, acoustic or haptic, but most of the time it is applied in a combined form. Feedthrough helps other players follow the current player's actions. Each kind of feedback depends on the environment it is used in. Furthermore, the right amount of feedback and feedthrough need to be applied at appropriate time.

11.6.10 Comfort of the Physical Setup

The construction of the setup (including the display) should be comfortable to be used and not hinder user while playing the game.

In this heuristic, we mainly focus on the hardware setup, which concerns the dimensions of the tabletop setup as well as the position of the player and the display system in use. The comfort is measured by the impressions of the current gamer. Players should feel comfortable during the entire duration of the game.

11.7 Conclusions

Digital tabletop games are emerging as both research projects and commercial efforts. In this chapter, we presented different approaches of how to develop interactive tabletop games. We reviewed several pieces of related work, describing two in detail. Finally, we presented heuristics for designing the many facets of tabletop games. These heuristics are drawn from our experiences and a review of the literature.

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