Acknowledgement

The author would like to extend his sincere gratitude the following people:

Supervisor, Prof Adrian David Cheok, for his guidance and contributions throughout my journey of self discovery.

Fellow graduate students James Teh, Khoo Eng Tat, Zhang Chengxi and Tim Merritt for their companionship and being there for me.

Fellow lab members like Dr Newton Fernando, Liu Wei, Choi Yongsoon, Janaka Prasad and Roshan Peiris for being around with me in the lab.

Mixed Reality Lab's MSO like Syikin and Rashika for their help and support rendered.

Students like Janyn Sen, Murrati Nguyen, Elvin Yio, Mickey Loi Huicong, Chewy Loh Chiu Weng, Chris Wu, Max Ng and King Chan for their monstrous help in manning the monsters.

Especially to Willi Ching Choon Yong, Dr May Win Naing, Dr Chee Chinyi and fellow friends from my MEng days for their help in making this journey possible.

Contents

Summary

The use of media to evoke emotions from the human audience/users (like a scary movie evoking fear and an exciting car racing video game that evokes excitement) gives birth to the term Empathetic Media. While there are lots of ways to evoke emotions using media (like creative pervasive game play between grandparents and grandchildren, haptic communication over the Internet, cute design for more engaging interface) Living Media as a means to make the human audience/users feel more (based on the empathy human beings feel for living creatures) is presented in this case. The study of Living Media rather than specifically giving an optimal solution to a well defined problem is presented as an exploration into the space of this domain instead. Iterations resulting in workable prototypes (two iterations are given) are presented, illustrating and highlighting the different dimensions of the design space of Living Media. This approach is what Fallman [1] refers to as design oriented research. Our first iteration, Metazoa Ludens, was built with the intention of providing a general understanding of the plausibility of the concept of Living Media to illustrate Empathetic Media. In addition we would like to investigate the linkage between the animals and the humans through the game so as to create an experience that is beneficial to both the animals and the humans. The second iteration, dDNA, explored Empathetic Media through use of glowing plants at an ambient setting and through the use of mapping humanistic information to the Living Media investigates the effectiveness of Empathetic Media coupling with humanistic information. Experimental studies were conducted using Csikszentmihalyi's Flow theory [2] as a basis for Metazoa Ludens as well as studies done to show benefits to the animal while a pilot user testing was conducted for dDNA. Results from both

projects show that overall the human users feels more for the Living Media proving our hypothesis correct. In addition the results were used to generalize design frameworks; from Metazoa Ludens a framework in general for human to animal interaction systems and from dDNA a framework for living media in general. These of which may provide the basis for future work to create even better human-animals/plants communication channels, build better relationships between human-animals/plants and even broader use of Living Media as an empathetic interactive media.

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Chapter 1

Introduction

1.1 Background

The scientific uncovering of emerging media imbued with artistic expression can be a path which challenges certain traditional paradigms and embraces a dangerous naivete of the artist that parallels to an incalculable alchemy of mind, machine and magic. Like the artist, we don't need to see it to believe it; we see it because we believe it. Despite the revolution of medias ignited by emerging science and technology, its horizon however are sparked by artistic imagination, the effects changing life inevitably and in ways which we never expect.

Imagine it is late at night and you are working late at home, deeply analysing a problem and trying very hard to solve it in front of your computer. You do not notice the fatigue building up within yourself and you have since long ago ignored the groaning of your stomach. The whole time there is a half filled tank sitting quietly beside your table in the background. Submerging within the tank are a few heads of red cabbages together with some zebra fishes swimming in the tank. The whole tank is known to you as "Baggage Cabbage", it seems calm and has left you alone for the most time which is fine to you. After a while instead of going forwards, your work seems to be going backwards also the little bits of failure and frustration are starting

to add up. You feel like you are not going anywhere. You look over to the tank and cannot help but notice the cabbages' colours are changing from a deep purplish to soothing light green while the zebra fishes are glowing in a calming mix of blue and green. You enjoyed the calming effect of the living display and soon you feel calmed and ready to be engaged in your work again.

Imagine now the same scenario but instead of living cabbages and fishes you have plastic cabbages and toy fishes. The plastic cabbages light up with light bulbs contained within while the toy fishes use LEDs. Would you have felt the same calmness?

Media these days while very engaging and entertaining sometimes lack emotional ties, empathy, to empathize with the human audience and vice versa. This is unlike the empathy one would feel for other living beings. Empathy have been proven capable of enhancing the power of media and enriching the interaction between the human and the media [3]. To have such a media which can make the human feel more the term Empathetic Media is thus born. In trying to make human feel more during interaction with the media using the empathy one would feel for living being we thus created Living Media.

Since eons ago we human beings have been living closely with the living nature. We plant flora around us, be it in the garden or as potted plants in our rooms. We interact with the fauna around us, keep them as pets and sometimes even rear them to work for us. The reason for this is due to the empathy we human beings have for other living being [4]. Imagine accidentally stepping onto an object like a shoe left on the floor, now imagine accidentally stepping onto the tail of a dog resting on the floor. The additional emotion one feels as the dog whimpers in pain is evidence of the empathy we human beings have for other living beings.

This research therefore aims at exploring Living Media using the empathy human beings feel for other living beings as a means to make the human audience feel more. That is to use Living Media as a means to Empathetic Media.

In the exploration of Living Media as Empathetic Media, design-oriented research approach [1] is used and a few iterations (two in this case) resulting in workable prototypes are developed. A first iteration will be to use animals or rather pets to be part of a system interacting with the human audience (to be discussed in greater details in Chapter 3). Small pets (in this case hamsters) are selected for this system which was named Metazoa Ludens. The overall concept of Metazoa Ludens is akin to a multi-player game where one of the online players is a pet hamster and the owner of the game will pit against his/her pet hamster in order to complete the game. Studies are next carried out on both the hamsters and the human in order to gather results for the purpose of testing the prior stated hypothesis (that the human audience feels more empathy towards Living Media). A framework is next drawn using the results to generalize design frameworks for any future human to animal interaction systems.

A second iteration named dDNA (to be discussed in greater details in Chapter 5) results in the use of bacteria to form part of the media (like an LCD screen) to convey various information to the human audience. *E. coli* with transformed DNA is being used in dDNA to form part of a living display for the purposes of expressing various information. Once again studies are carried out and from the results a general framework is formed for living media in general.

1.2 Objectives

This project aims to establish the following:

1. To develop Metazoa Ludens, a system for interaction between humans and animals for the testing of empathy in Living Media.

2. To develop dDNA, a system using media which is alive as a display for expressing various information.

3. Testing of the hypothesis that audiences feel more empathy for Living Media than non-living ones.

4. Develop generalised frameworks for human-animal interaction systems and living media.

1.3 Scope

The scope of this project is restricted as follows:

i) Veracity of Telepresence: Like all remote interaction system, one main concern with Metazoa Ludens 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 however is a generic one existing in most remote interaction system and has been extensively discussed in other works [5], [6] more focused on telepresence, and thus the author feels it is out of the context of this thesis.

ii) Pets' Choice: The method of Duncan [7] has been used in Metazoa Ludens' testing which allows the hamsters a choice to return to their cages should at any point of time they do not wish to interact with the human using Metazoa Ludens. While this does not mean that explicit consent has been obtained from the hamsters to use them in Metazoa Ludens, nonetheless what is highlighted is a generic issue: the issue of explicit communication with animals to obtain their rights and consent for human-animals interaction (which is prevalent in most human-animals interaction like animals shows in the zoo). While it is important that animal rights are observed, until there is better and more effective way of communicating with animals the

method of Duncan is deemed sufficient to test hamsters' consent/choice in using Metazoa Ludens.

iii) Ethics of animals/plants research: While under certain circumstances it might be unethical to be changing/transfroming the dna of living beings, however in the case of dDNA only dna of *E. coli* are transformed which are primarily primitive plant organisms. Also all work done for both Metazoa Ludens and dDNA are in full consideration of ethical issues with approval by the university's Institutional Animal Care and Use Committee (IACUC) and in accordance to the USA Animal Welfare Regulations [8].

iv) Scope of Frameworks: The generalized frameworks for both human-animal interaction system and living media given are derived from a selected lists of systems given in the literature reviews of the thesis. While this list may not be extensive, the systems chosen are not intended to be an exhaustive listing of all human-animals and living media systems. As while having an exhaustive list give completeness it may not be required for the development of a design framework.

1.4 Organisation of the Thesis

The thesis is organised as follows:

Chapter 1 gives an introduction to the use of Living Media as a means to convey Empathetic Media.

Chapter 2 gives the design process of the research work for Living Media done for this thesis.

Chapter 3 gives the conceptual and technical details of the Metazoa Ludens system.

Chapter 4 provides the user studies results of Metazoa Ludens and the framework for human-animal interaction system.

Chapter 5 gives the conceptual and technical details of the dDNA system.

Chapter 6 provides the user studies results of dDNA and the framework for Living Media system.

Chapter 7 presents the conclusions of the thesis, the thesis's contribution to knowledge as well as possible future works.

Chapter 2

Living Media and the Design Process

This chapter will reveal the flow of thoughts which eventually lead to the research direction of this thesis and also address the design process for the research works (Metazoa Ludens and dDNA) presented. The larger research area in which the research works are in is first identified before moving onto discussing the methods used in the research works.

2.1 Background of Empathetic Media and Living Media

Through deep scientific research, emerging media has always revolutionize the way people live. From the telephone invented by Alexander Graham Bell for real-time remote communication to motion pictures for capturing sequences of live motions to the Internet almost two decades ago and currently to the latest Nintendo Wii [9] which totally paths a new way for playing video games in front of the TV.

In this wide spread spectrum through which media can affect our lives, on one side we get findings on how violent depictions on media (like in movies or video games) can increase aggression behaviours and hostile personalities thereby negatively influencing the human audience [10]. On another side we have findings on the use of empathy in media which not only increases knowledge but influences stigma reduction in given discriminated groups of people thereby positively influencing the human audience [11]. In view of this our general research direction steers towards the latter: in using empathy in media to positively affect the human audience.

Empathy refers to situation in which the subject has a similar emotional state to an object as a result of perception of the object's situation or predicament. The distinction between self and other is maintained and the emotional state remains object focused rather than self focused [12].

On the other hand empathy as used in the media has been shown to help educate and reduce discrimination [11]. It has also been proven that empathy holds the key to adolescents in their own selection of positive role models as depicted in the media whom which they based their own identities and behaviours on [13]. Furthermore empathy is shown to be the key component in making communication media such as Instant Messaging enjoyable and harmonious [3]. Also empathy used in media for design processes has been shown to prevent project failures [14]. In addition based on a study on online communication between old people about depression, media and technology has been shown to be capable of spreading empathy among people [15]. Based on these it would thus seem like empathy could play a key role in the positive affectiveness of the media.

As according to Post *et al.* [12] "In today's era of email, commuting, frequent moves and bedroom communities, the scales are being increasingly tipped against the automatic and accurate perception of others, without which empathy is impossible." We thus propose a path towards embedding empathy in media, the term Empathetic Media is thus born and it would define any media capable of making the audience feel with or for the content of the media and possibly allowing the audience to

respond in a congruent way.

Research done by Peloquin [16] explains that it follows three general rules to develop empathy within the human audience: firstly to use one's own senses to grasp the feeling; secondly to stretch the imagination to see a new perspective; thirdly to visit the new perspective and occupy it to enhance understanding. On the other hand research done by Yasuhiro [17] shows the possibility of embedding empathy into technology and media. It consists of two aspects: firstly to transfer subjective and personal individual experience by utilizing media technology; secondly to recreate (new) experiences and emotions by means of the media technology. Therefore putting the two together it can be deduced that to develop empathy within the human audience using technology and media, firstly the utilized media technology needs to be able to capture the feeling of the human audience. After this the imagination of the audience is stretched and allowed to be occupied within the space as created by the given media technology, thereby recreating certain new perspectives, experiences, and emotions within the human audience for better understanding.

This suggests the importance of the media technology utilized as firstly it needs to be a tool capable of capturing the humans' subjective feelings. Secondly it needs to be a tool which is capable of using the feelings "captured" to recreate certain experiences and emotions. The design and content of the media technology is thus crucial in defining itself as Empathetic Media. Furthermore this is not a clear well-defined research problem which can be solved or approximated by a single optimal solution. Rather this is a byzantine domain which needs vigorous investigation such that the various possible dimensions and aspects may be uncovered. A design-oriented research approach is thus employed since this approach allows deep exploration without a very specific aim of solving a well-defined problem (this will be discussed more in details in the later part of this Chapter).

In the meanwhile there could be numerous means and ways to create content within the media technology to create empathy. While it is great to have research on a complete spectrum of content possible to create Empathetic Media, an exhaustive

list may be unnecessary and impractical at this stage. Instead a general focus will be selected and researched upon in our exploration of Empathetic Media. To select a suitable general focus, empathy is reexamined.

Empathy arises from group living / cooperative social species where it is to the advantage of members of the group to be able to be emotionally affected by the distress of another member of the group; it also facilitates group movement essential for the survival of the group [12]. In addition empathy has been uncovered to be shown across various species and not just among human beings [18] and even between human, plants and the environment [19]. It was also discovered that empathy shown towards animals (horses and dogs in this case) is able to help the human subjects cope better with their mental and emotional needs [20]. Additionally evoking empathy for a natural object (be it a bird or tree) demonstrates a greater willingness to act in ways to protect the environment [19]. Furthermore interactions with natural object (animals in this case) help positively influence psychological and physiological parameters important to health and welfare of human [21].

In reflection, our primary goal for researching into Empathetic Media is towards the direction of positively influencing the human audience. Based on literature reviewed given above we are motivated to incorporate human and nature interaction into our research as the content for the media technology. Such interaction may prove to not just enable us to explore Empathetic Media but create positive influence to the human audience as well. As such we developed the concept of Living Media, that is any system which has parts of it made up of living beings with an aim of using the empathy human beings feel for other living beings, as a means to make the human audience feel more for the system.

Hence we used a new concept of Living Media for exploring Empathetic Media. It is like seeing a real biological rose in a vase versus seeing a plastic artificial rose in the same vase - will being alive make the audience feel more for the system relative to one which does not contain any media that is alive? In order to answer this a living media system needs to be built. This allows the exploration of Living Media

as a means to Empathetic Media, the results of which could give new means of interaction between human and nature as well as new forms of interactive media.

Having arrived at Living Media as the main research focus for our work, the next section discusses about the design process used to explore deeper into Living Media.

2.2 Design Process

The research works on Living Media presented in this thesis adopts a design-oriented research approach where through the process of designing, implementing and evaluating workable prototypes, knowledge is gained [1]. It is important to note while the research presented here is not aimed at solving a well-defined problem, the prototypes thus implemented are not a means to an end of a problem. Rather the design space for Living Media are examined resulting in various prototypes (two in this case), illustrating and highlighting the different dimensions of the design space of Living Media. This approach is what Fallman [1] refers to as design oriented research:

"In design-oriented research, the knowledge that comes from studying the designed artefact in use or from the process of bringing the product into being is the contribution, while the resulting artifact is considered more a means than an end."

This examination of the design space has been carried out much in a fashion of an iterative process making up of four steps [22]:

1) Formulating objectives, research questions and/or working hypotheses

2) Design and implementation of a functional prototype

3) User studies

4) Analysis and reflection

New knowledge is gained throughout the four steps and not just limited to the final step. The new knowledge gained will further result in new research questions which will bring about new prototypes and hence further examination of the design space. This exploration of the design space is thus an iterative process.

2.3 Formulating objectives, research questions and working hypotheses

The formulating of objectives, research questions and working hypotheses is crucial to our exploration of the design space. Various iterations are done in our continued exploration into Living Media. Our first iteration results in a working prototype named Metazoa Ludens (more details in Chapter 3). It was built with the intention of providing a general understanding of the plausibility of the concept of Living Media to illustrate Empathetic Media. In addition we would like to investigate the linkage between the animals and the humans through the system so as to create an experience that is beneficial to both the animals and the humans. The second iteration gives a working prototype named dDNA (more details in Chapter 5). It explored Empathetic Media through use of Living Media at an ambient setting and through the use of mapping humanistic information to the Living Media investigate the effectiveness of Empathetic Media coupling with humanistic information. Our general hypothesis applicable for both iterations is that due to the empathy human beings feel for other living beings (be it plant or animals), human beings will feel more for Living Media than a media which does not have living components. The first iteration, Metazoa Ludens, have lead to a general understanding of the use of Living Media where users feel more due to the game play with other living beings. This led to the design of dDNA which is to further explore this empathy feeling humans have for living being and how this empathy may be further extended for a greater application. A second hypothesis more specific to the second iteration

is thus derived. We proposed when Living Media is used to represent humanistic information (like communication levels between loved ones, or a person's cholesterol level) the information represented will have a greater impact on the human due to the empathy that human feels for living beings. For example a person seeing a flower withering and knowing that the withering state of the flower represents the communication level between she and her loved ones, she may then make extra effort to communicate more between she and her loved ones.

Hence through iterations, more dimensions of the design space of Living Media are explored and uncovered, leading to further formulation of new hypotheses and new research questions. The result of which is far more than the resultant working prototypes, but the knowledge gained which could then be used to improve the way human and nature (animals/plants) interact as well as introducing other means of media for interaction.

2.4 Design and implementation of functional prototypes

The next step involves the design, implementation and performance testing of a functional prototype as a result of each iteration.

2.4.1 Concept and design

This thesis explores the potential to provide experiences rather than task efficiency [23]. This means that not only is an advanced technical solution needed, design concepts which provides for interesting and challenging interaction is explored. However the design concepts themselves have to be an important part of the research and satisfy certain objectives. To this end objectives of the iterations are established through literature review of related works. From the objectives user

interaction scenarios are envisioned. Based on the user interaction scenarios the requirements will be uncovered which thus form the design concepts for the iteration. These are further detailed in Chapter 3 and Chapter 5 of the thesis.

2.4.2 Implementation

The design concepts are next implemented as a functional prototype. The prototype will allow the exploration of the design space of Living Media by trying out hypotheses and technical solutions on the human interaction with Living Media. The prototype also serve as a concrete manifestation of the research concept of Living Media. Precise implementation of both the iterations presented in this thesis are discussed in Chapter 3 and Chapter 5 of the thesis.

2.5 User studies

User studies take place once the prototype has been implemented. The purpose to this is to learn about the usage in a real-life situation. This not only provide feedback on the implementation and the design, it allows the testing of hypotheses through well formulated survey questions or interviews from which insight on future design as well as knowledge on the design space for Living Media may be uncovered.

For the first iteration four separate tests are carried out for user studies. Firstly body condition score testing is used to study the effect of the first prototype on the health condition of the hamster [24]. Secondly the method of Duncan [7] is used to test for the pet's choice to interact with the human audience via the first prototype. Thirdly a survey using Game Flow theory based on Csikszentmihalyi's Flow [2] is used to assess the human users enjoyment of the system. Lastly a survey is used to assess the empathy users feel for the pet as a result of using the system.

For the second iteration a questionnaire made up of a mixed of open and closed ended questions is used in order to understand the general aspects of the users' opinions. The questionnaire is basically focused at answering the five design questions of the second iteration. More details about the user studies for both iterations may be found in Chapter 4 and Chapter 6 of the thesis.

2.6 Analysis and reflection

The fourth activity involves analyzing and reflecting on the conducted work. Unlike the rest this activity is ongoing concurrently with the rest of the activities, like user studies result in analysis and reflection of the design, concepts and knowledge thus gained from the two iterations. However more prominently this fourth activity is displayed at the end of each iteration where a framework was drawn up as a result of analysing and reflecting upon the prototype thus done.

In Chapter 4 a framework for human-animal interaction system is drawn based on both literature reviewed as well as the building and usage of the first prototype, Metazoa Ludens. Five design dimensions are first derived from re-examining the system from design stage to finally implementation stage. Similar human-animal interaction systems obtained from literature review are then positioned based on the given dimensions. With the given positions of the human-animal interaction systems four clusters are identified and four design patterns are obtained. This therefore form the basis of the human-animal interaction system framework.

Similarly in Chapter 6 a framework for living media design is drawn based on both literature reviewed as well as the building and usage of the second prototype, dDNA. Like before design dimensions are first derived from the study of the system as a whole. Other similar systems from literature review are then positioned based on the given dimensions from which design patterns are obtained.

These therefore would be used as a basis for future work relating to Living Media

in the form of generalization as well as to give insights to Living Media for future elaboration.

Chapter 3

Metazoa Ludens

This chapter discusses the first iteration and the first working prototype named Metazoa Ludens, from the background to the conceptual design to the technical details and finally to the user experience of the system.

3.1 Introduction

The use of Living Media to demonstrate Empathetic Media arise from the ability of human beings to show empathy towards nature (animals and plants) and from there derive positivity from interacting with nature (as discussed in Chapter 2). Having chosen Living Media as a means to explore Empathetic Media we move onto our first iteration in exploring the design space of Living Media. Our primary objective of using Living Media is to get a general understanding of the plausibility of the concept of Living Media to illustrate Empathetic Media. Our first goal therefore is to establish that by using a media system which has living components (that is Living Media), the audience is thus able to feel for the content of the media and possibly respond in a congruent way. Our first iteration will therefore work towards answering that question with a working prototype.

To build a working prototype on Living Media the definition of Living Media is examined. In a broad definition a living media system is a media with living organisms. In retrospect this definition could be interpreted in many different ways and to complicate matters there could be many ways to realize this definition as a real working system. However at the first iteration we adopt a more straight forward and easy to understand look at Living Media.

Pondering upon the possible use of Living Media in general before this point in time, it is realized that even before the age of machineries and advanced technology human being has relied heavily on animals as a means of performing tasks e.g. horses to pull carts and carriages, oxen to plough the fields, dogs to guard houses and so on. Such are 'systems' which have parts of it performed by living beings and hence could in a straight forward and easy to understand way fall into the broad definition of living media systems. Furthermore their human owners do feel more for these animals/pets due to the intricate working relationship thus developed from these "systems". This hints on the possibility of empathy shown in using these "systems" (this will be discussed more in the later part of this chapter) further implying the research direction towards Living Media may lead to Empathetic Media. Our first iteration could look at Living Media in the direction of such living media systems as discussed. The Living Media will therefore be seen as a system whereby one specific component of it is made up of an animal interacting with that system. This interaction will contribute to the working of the overall system thereby allowing a human to interact with the animal through the system. Such a "human-animal interaction system" will therefore be built as the first working prototype for the first iteration of Living Media. (It is noted that while Living Media is not entirely made up of only animals, for the ease of getting started with the first iteration the more straight forward human-animal interaction system is explored; exploration of bacteria as Living Media is given later in Chapter 5).

We next go on to reviewing related literature from which an overview design concept for the first working prototype is derived.

3.2 Literature Review

The literature review that follows is made up of two main parts: the first part is a study on works done on human-animal interaction. The study provides evidence on the benefits of human-animal interaction and eventually arriving at the conclusion of building a human-animal interaction system for our first iteration of study in Living Media.

The second part discusses on work done on related human-animal interaction systems. This includes a brief look at non-technologically enhanced conventional 'human-animal interaction system' before moving onto discussing various work relating to digitally enhanced human-animal interaction system. (This discussion does include related studies based on human-human interaction system. While extensive literature is available for human-human interaction systems nonetheless it is a separate area of studies by itself as such only relevant human-human interaction system will be discussed and/or compared with the reviewed human-animal interaction system.)

The study on human-animal interaction system first look at various digitally enhanced human-animal interaction system (like systems based on mixed reality). It then moves on to discuss relevant works related to remote human-animal interaction system.

3.2.1 Benefits of human-animal interaction

Human-animal interaction (mainly between human and their pets at a social level) offers many benefits for both the pets/animals and humans [25, 26]. During the 1980s, animals' roles in therapy gain more recognition as a distinction between animal-assisted activities (AAA) and animal-assisted therapy (AAT) was made [27]. This shows the beneficial impact of human-animal interaction on humans such that it is used as a means to help patients. AAA provides opportunities for motivational,

educational, recreational and therapeutic benefits to enhance 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 shows that the empathy from human-animal interaction given is able to reduce violent behaviours and frictions in the prison. It is also capable of reducing medication and increasing appropriate social conscience for the inmates [28].

Another study using prisoners to take care of and train animals (horses and dogs in this case) shows that due to empathy resulting from the human-animal interaction there were not only gained in life-enhancing skills but reduction in recidivism as well. It also shows that empathy resulting from the human-animal interaction is able to help the people cope with physical and emotional needs [20]. These show that human-animal interaction can be used in therapy setting to teach new skills or to reduce maladaptive behaviors [27].

Research demonstrated that not only is empathy from human-animal interaction capable of improving the psychological and physiological parameters important to health and welfare, it has been proven to give positive results in using animals to assist in therapy (AAT) as a form of alternative therapy [21].

Besides being used in researches and therapies, empathy from human-animal interaction in a social context is shown to be beneficial to the general population. Most human-animal interaction at a social level occurs between human and animals kept as pets. Through interaction with pets, pet owners are generally given social support and unconditional acceptance by their pets which have some advantages compared to the social support given by humans. This is so as pets accept their human owners without much criticism while fellow human has the tendency to give much judgement [29].

Furthermore interaction with pets satisfy human being's need to nurture: while

evidence shows that self-esteem is an important aspect of social emotional development of children on the other hand it is uncovered that children's self-esteem scores increased significantly over a 9-month period of keeping pets and interacting with the pets in their school classroom [30]. Additionally many parents admit that interaction with pets gives children valuable lessons about life events [31]. More often than not, the bonding shared between a human and his/her pet as a result of empathy is such that the owner is as close to the pet as the owner is to his/her closest family member [32]. In addition pets do provide companionship and the empathy thus induced helps reduce level of loneliness among their owners who interact frequently with them [33]. Another study shows that the empathy induced from interaction with pets helps reduce stress and anxiety level among their owners [34].

On a physiological health level, human-animal interaction (pet dogs in this case) are able to help reduce the level of blood pressure of the owners thereby reducing the risk of hypertension [35]. In addition, interaction with pets (termed"pet effect" in this case) is found out to be beneficial to the cardiovascular conditions of the pets' owners [36] and bring about a significant reduction in minor health problems for their owners [37]. These once again reinforce the beneficial impact of human-animal interaction on human beings.

3.2.2 Requirement for remote human-animal interaction

While the benefits of empathy from human-animal interaction are much noted nonetheless literature reviewed reveals that there are not many technological innovation made in enhancing human-animal interaction (this is discussed in details in the literature review of human-animal interaction system given in the later part of this chapter). Rather such technologically enhanced interaction systems are generally restricted to human-human interaction and not extended to promote human-animal interaction.

Animals kept as pets are generally neglected and taken for granted by the pets'

owners due to the rapid advancement of technology [38] which is changing the way people live and making the pace of life even faster. Furthermore longer working hours are expected in the professional world in order to match up with this faster pace of life (thus caused by technology advancement) [39]. In addition, globalization as advocated by technology has caused an increased in professionals across the globe on business trips [40]. Due to this general change in the professional lifestyle humans are out of the house for longer hours and this means less time spent with their pets back at home [38]. However, animals, like human beings, need love and care [41] as well as a good dose of exercise with a suitable diet to ensure healthy living [42]. With this negligence, pets will be deprived of the love and care they so required from their human families [41].

All in all we are currently given a situation whereby technology advancement has brought human away from interacting with pets/animals. The changed lifestyle of humans are experiencing negative problems while foregoing the mentioned benefits of the empathy from human-animal interaction. Unbeknownst to most such negligence of pets may be more of a losing end to the owners than the pets. Since as discussed previously interaction with pets/animals can provide companionship, offer non-judgmental acceptance, help boast self-esteem and give love as well as help lower the level of stress and social strain experienced by their owners. Yet with this simple inattentiveness a great number of positive consequences are foregone. Nonetheless while acknowledging advanced technology's negative effects one cannot deny its fitful integration into the society. As such what arises is the need to bridge the gap between the progressions of our lifestyles and our connection with our pets for the balance of our well being. The assessment of such a situation would lead to a conclusion: to embrace and celebrate technology since there is no way to make it go away; yet in an attempt to make the world a better place, medias/technologies thus devised should address and mend (or minimize) the growing gaps within the society empathetically as caused by isolation deprived from advanced technology. Without compromising on the actualities of technological sophistication we move to attempt to mend this gap by researching into human-animal interaction system to

give empathy (that is empathetic Living Media). By incorporating human-animal interaction into a system it not only aims to evolve the bonds humans share with animals it also aims to bring media technology to the next level. This will have positive effects on the users and is capable of bettering the quality of life.

This system in discussion could give a different connectivity and form of interaction between human and animals relative to existing ones. Furthermore advanced technology (like mixed reality) may be added as elements of the interaction system. This will allow different forms of interaction to be introduced for example the animals may be allowed to "chase after" the human owners in a digital world (which is impossible in the physical world). Such interaction may be even extended to remote interaction over the Internet (this could help solve the problem of pet owners going on business trips and are not able to interact with their pets back at home).

Such a system forms the basis of our first working prototype which we named Metazoa Ludens. Metazoa in biology means multicellular organism which is simply to mean animals, Ludens comes from the phrase "Homo Ludens" which by itself Ludens means to play, thus Metazoa Ludens simply stands for to play with animals. With Metazoa Ludens we hope to allow interaction between human and animals and induce empathy through a digital interface in a mixed reality manner which is different from the conventional human-animal interaction. This we hope shall advocate Living Media and path the way for greater improvement between the way human and animals interact through advanced digital media.

The literature review next moves onto uncover related work and other human-animal interaction systems. This allows the gathering of previous knowledge learnt from similar works in preparation for the building of the first working prototype.

3.2.3 Works relating to human-animal interaction system

Current human-animal interaction between human and animals at a social level mostly involve simple games between pets and pet-owners to the likes of fetch, or

chasing squeaky rubber toys. A more established tool-based interaction used for training dogs known as clicker training [43] uses a click sound made just before a treat is given. Nonetheless all these interactions with animals/pets do not utilize sophisticated technology and their sole purpose lies toward entertainment - no deliberation or whatsoever are intentionally for empathy resulting from human-animal interaction or advocating it for that matter.

On the other hand, using sophisticated technology may be useful for enriching interaction between animals and humans as it could add on to the existing ways of interaction by offering enriching experiences that high-tech devices are capable of giving. A brief look at digitally enhanced sophisticated human-human interaction systems (like mixed reality systems) shows that Human Pacman [44] and "Can You See Me Now?" [45] are pioneers of mixed reality games that allow remote/web players to interact with players participating in the game in a more physical and ubiquitous manner. In Human Pacman 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 of virtual cookies and coins (for Pacman's collection). While in "Can You See Me Now?" physical players chase remote avatars of web players. These works show how it is possible to enhance interaction greatly using technology to achieve ubiquitous interaction and move beyond the existing digital interaction where one sits in front of the computer or TV screen and uses keyboard, mouse or joystick.

Other mixed reality games soon follow suit like Sports Over a Distance [46] which allows people who are miles apart to play a physically exhausting ball game together through a common screen; Age Invaders [47] which allows grandparents and grandchildren to interact on a mixed reality interaction platform playing the traditional game of Space Invaders; Lover's Cups [48] is a project that allows people to share the time of drinking with someone remotely, as one drinks from his/her cup the other cup held by the remote party will glow. These projects represent a shift of research focus on not just creating something novel and innovative but studying a deeper issues as embodied by system thus created. In Sports Over a Distance

it studies not only the positive health effects that the system has to offer to its users but more importantly the impact on social bonding between the players. In creating computer augmented devices this project studies how such devices can lead to new sport experiences and explored opportunities to combine physical activities with remote social bonding, this gives the basis for the future Exertion Interface as explored by the same group. In Age Invaders it is not just a novel family entertainment system with a novel mixed reality interaction platform, it aims to explore the links and ties a grandparent shares with a grandchild, and aims to close up any generation gap and to help promote intergenerational interaction using digital technology. Lover's Cups while demonstrating a unique invention in remote interaction at a deeper level aims to promote affection especially for lovers separate by physical distance. From these examples we saw that not only can sophisticated technology be used to enhance the interaction between human and animals, but more importantly using sophisticated technology (to build a human-animal interaction system) could be seen as a means to study and understand the empathy from human-animal interaction which gives the basis for Living Media. We thus move on to explore other sophisticated human-animal/pet interaction system.

A look at relevant existing sophisticated human-animal/pet interaction system results in the following: Rover@Home [43] is a system using common communication tools such as webcam, microphones and speakers to allow communication to dogs over a network. In the project carried out a user will interact with the dog over the network and responses of the dog was noted. This allowed a study of the autonomous responses from the dog for the purpose of creating autonomous online virtual characters. Studies carried out thus did not involve in human-animal interaction and empathy rather was for the purpose of development for artificial intelligence for virtual characters.

Infiltrate [49] is a system which displays a virtual scene from the point of view of a fish from a fish 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 to the general interaction one has with fishes (that is interaction is

nothing more than the owner viewing a swimming display), it offers no form of interaction between the audience and the fishes or the display screen other than a simple viewing of the tank through the fish's eyes.

In Cricket-Controlled Pacman [50], a human player plays the traditional computer game of Pacman with real live crickets in a mixed reality game. The crickets play the role of the ghosts and run in a real maze while the human play the role of the pacman and controls the 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 out of fear and moving in random directions. In retrospect, a positive motivation may be a better choice over a negative motivation to persuade the animals to play the game. To take this one step even further benefits (like good health due to more regular exercises) may be incorporated to ensure the animals the system will be positive for the animals.

Hamster-powered phone charger [51] is a project whereby a hamster runs on its exercise wheel while a cell phone attached to the wheel gets charged. Although this is a simple project and was done at a high school level however the inventor of the project commented that at times when the hamster is not running on the exercise wheel, the cell phone will not be charged and he will not be able to make phone calls. Even though this is not the main focus of the project however it reveals implicitly that the hamster is given a choice to use the system - the hamster only runs the exercise wheel and help charge the cell phone when it wants to. While the statement may sound straight forward however it points to the very fact that the hamster not made to use the system for the benefit/entertainment of human but rather has a say in it. This is something which is very crucial when dealing with animals (of which a lot of other human-animal interaction system fail to discuss) since while creating human-animal interaction system to enhance human-animal interaction we should

make sure the systems created are not done mainly for the benefit/entertainment of the human and the animals are made to use the system regardless of choice.

From these examples of human-animal/pet interaction system we have learned that: with Rover@home, which is used to study autonomous online character for the purpose of artificial intelligence, it is possible to use technology to create human-animal interaction system in order to study a higher issue (like Empathy) rather than just showing the technicality of creating a novel project. With Infiltrate while it remains true to the conventional interaction one has with fishes it may be useful to have a system that advocates interaction. This will give a better understanding of the interaction between human and the animal in question which in turn allow studying of empathy between human and the animal. For cricket pacman the inference drawn is that a positive motivation should be used rather than a negative motivation. As for Hamster-powered phone charger we learn that the animal involved should always be given a choice to use the interaction system. The animals involved should always be given as much consideration as if they are human users else the whole project will just seem like using the animals for the entertainment of humans.

Alternative technically sophisticated works of human-animal interaction mostly involve non-living electronic/virtual pets like AIBO [52], Tamagotchis [53] and Furby [54] 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 [55] who introduced a robotic teddy bear for interpersonal communication and Druin [56] 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 [54]. Behrens [53] 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 [38]. For the studies done on a group of children owning a Furby, it was found out 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 [54]. This thus show that a difference in perception and expectation between living and robotic pet companions still exists. In addition even though it was found out 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 human and real pets [57].

As reviewed the main point in such virtual/robotic human-'animal' interaction system is that they lack the rich interaction that exist between live animals and humans hence it may not be useful for the studies of empathy resulting from human-animal interaction.

As mentioned earlier just as the advancement of the modern world has brought many working professionals across the globes, it has also brought many 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 the human-animal interaction system. As such we moved into investigating another area within human-animal interaction system that is remote human-animal interaction system. Such systems involve interaction over great distances mostly via the Internet.

With Poultry.Internet [38] an interactive system is developed for remote human-animal (chicken in this case) interaction through the Internet. Humans can pat their pet chicken while away in office or business trips through the Internet via a pet jacket which the pet chicken is wearing. The Petting Zoo [58] 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 [59] 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.

In SNIF [60], 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 [61] is 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 wastes 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.

Generally these human-animal interactive systems only provide a one-way interaction, the animals have no way of interacting remotely with the humans or responding to the humans' actions. Looking at relevant remote human-human interaction systems we have PSybench [62] is an augmented table top where virtual objects on the tabletop are physically synchronised with real physical object on another remote tabletop. Players can then cooperatively manipulate a shared physical space remotely. InTouch [63] uses force-feedback technology to create the illusion that users, separated by distance, are interacting with a shared physical object. The "shared" object provides a haptic link between geographically distributed users, opening up a channel for physical expression over distance. For Denta Dentata [64] squeezing is transmitted via the device remotely from one location to another using a one bit information sent over the phone line. For the reason that communication

between two human users is more interesting if it is two-way rather than one-way such human-human interaction systems as discussed above have taken that into consideration. On the other hand remote human-animal interactive systems have yet to catch up with respect to that. Interaction would definitely be more enriching if both parties are able to respond at the same level rather than one sided be it between human-human or human-animals. More importantly none of these remote human-animal interaction systems as described aimed at moving in deeper and studying higher level issues like empathy, they mainly focused on a more superficial level of creating human-animal interaction system.

Building upon all these pet-human interactive systems, the first working prototype should extend and augment them by allowing bidirectional interaction between pet owners and their pets via interacting through an advanced technology enabled system (like a computer game) locally or remotely. It should be noted that this first system should be an interface meant for the benefits of the pets as well as in promotion of the awareness of digital human-animal interaction. Positive motivation is employed throughout the prototype such that the pets interact with the prototype willingly, and not out of fear or agitation. In addition, the prototype should ensure healthy exercise to the pets which are beneficial for the well being of the pets. From here a more concrete set of objectives are derived and given in the next section.

3.3 Objectives

Metazoa Ludens (see Figure 3.1, actual gameplay will be discussed in greater detail at the later part of this chapter) is a prototype that enables humans to play games with 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 means to investigate Living Media as Empathetic Media as well as 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

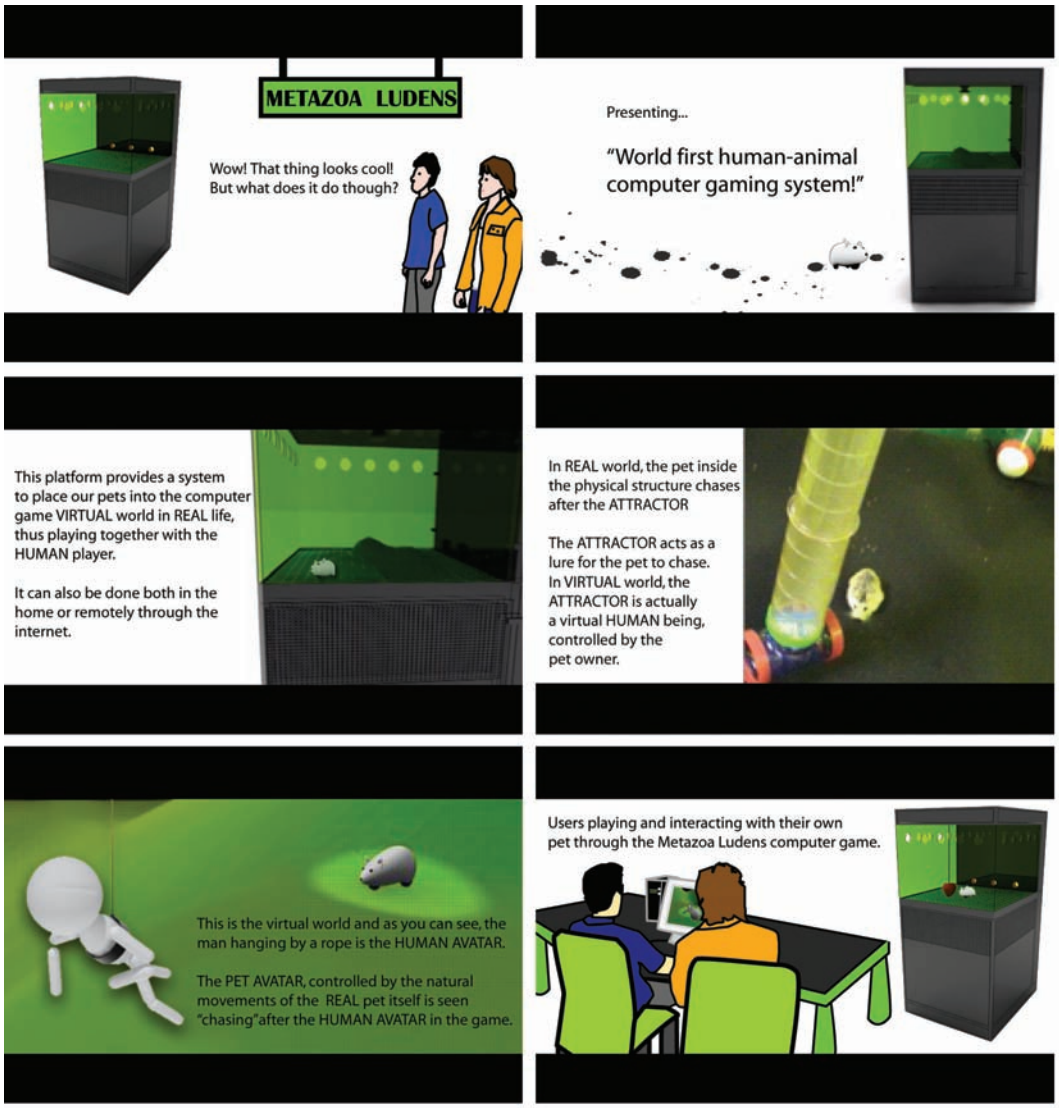

Figure 3.1: Users' Experience

human-animal interaction, taking into consideration the different physiological and psychological make-up between humans and their pets especially smaller animals (see below), and the way they may interact with the interface to evoke emotions especially in the human users/audience. While considering the human users' emotions however the animals feelings are not to be neglected, there should be a choice given to the animals to start playing the game should at any one time they choose to play. It is also the aim of the project that the prototype will not only provide a way for humans to interact remotely with their pets but also provide health benefits to the pets.

As such four general hypotheses are derived. First and foremost the pets' well being is put forth and considered. As Metazoa Ludens is developed with the objective of providing health benefits to the pets therefore the first hypothesis will be that pets interacting with human using Metazoa Ludens will gain health benefits after regular use.

Secondly since the different physiological and psychological make-up between humans and the pets are taken into consideration to create a Living Media to evoke emotions hence from the pets' point of view Metazoa Ludens would be engaging such that the pets would want to play the game out of their own free will (rather than being forced to play the game by the human owners). A way known as the Method of Duncan [7] to test such free will of animals may be employed. In the testing environment, a minor obstacle (like the simple act of going through an open door) is being placed between an animal and the action in question. For example hens may be 'asked' how much they value access to the litter through the blue door and red door test. The litter is placed behind the blue door, and by seeing how often the hen go through the blue door for the litter instead of the red door, it will give an indication of how much the hen valued accessing to the litter. Hence our second hypothesis will be that by using Method of Duncan the pet playing Metazoa Ludens will not only be given free will to play the game but will show positive motivation to play the game.

Thirdly one objective of developing Metazoa Ludens is to test the enjoyment of the human audience in playing with their pets using Metazoa Ludens. Our third hypothesis is thus that the human audience will enjoy Metazoa Ludens more due to the human-animal interaction.

Fourthly the main objective of developing Metazoa Ludens is to test Living Media as Empathetic Media hence our forth hypothesis is thus that the human audience will feel empathy to the pet avatars used in Metazoa Ludens controlled by live pets more due to the human-animal interaction therefore showing that Living Media is capable of evoking emotions in its audience.

Testing of these hypotheses will be discussed in Chapter 4. We next move on to the choice of pets for interaction in Metazoa Ludens.

3.4 Choice of pets

This research is aimed in general for 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 their cages unlike dogs and cats 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 [65]. 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 [66]
- Hamsters have a natural instinct to be skillful intelligent runners, which is very suitable for fun game play with humans [67]
- Hamsters' natural habitat are burrows that have many tunnels and one of their natural behaviors is to tunnel [65]. 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. [65]

Metazoa Ludens is thus devised as a mixed reality game for pets (hamsters) to play games with their human owners and as our first iteration into the exploration of Living Media as Empathetic Media. We next look at the design of the game based on scenarios we would like the prototype to achieve.

3.5 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' (human and hamsters) interaction needs, and hence are given consideration in the prototype's interface design.

3.5.1 Remote interaction

Marie finally gets back to her hotel room in Tokyo after a whole day of meeting on her business trip. She turns on her Metazoa Ludens system and immediately she gets connected to her beloved pet hamsters back in her home (thousands of miles away in Los Angeles) and 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.

3.5.2 Pet's choice

It is mid-afternoon and Mandy's pet, Fluffy, feels it is time to play Metazoa Ludens with Mandy. With that she choses to start the game with Mandy and move 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.

3.5.3 Pet interface

After one month of using Metazoa Ludens, Billy noticed that his pet hamster is less obese and more active than before. In addition each time his hamster is more than willing to leave the cage to play Metazoa Ludens with Billy.

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 obese-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 [68]. 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

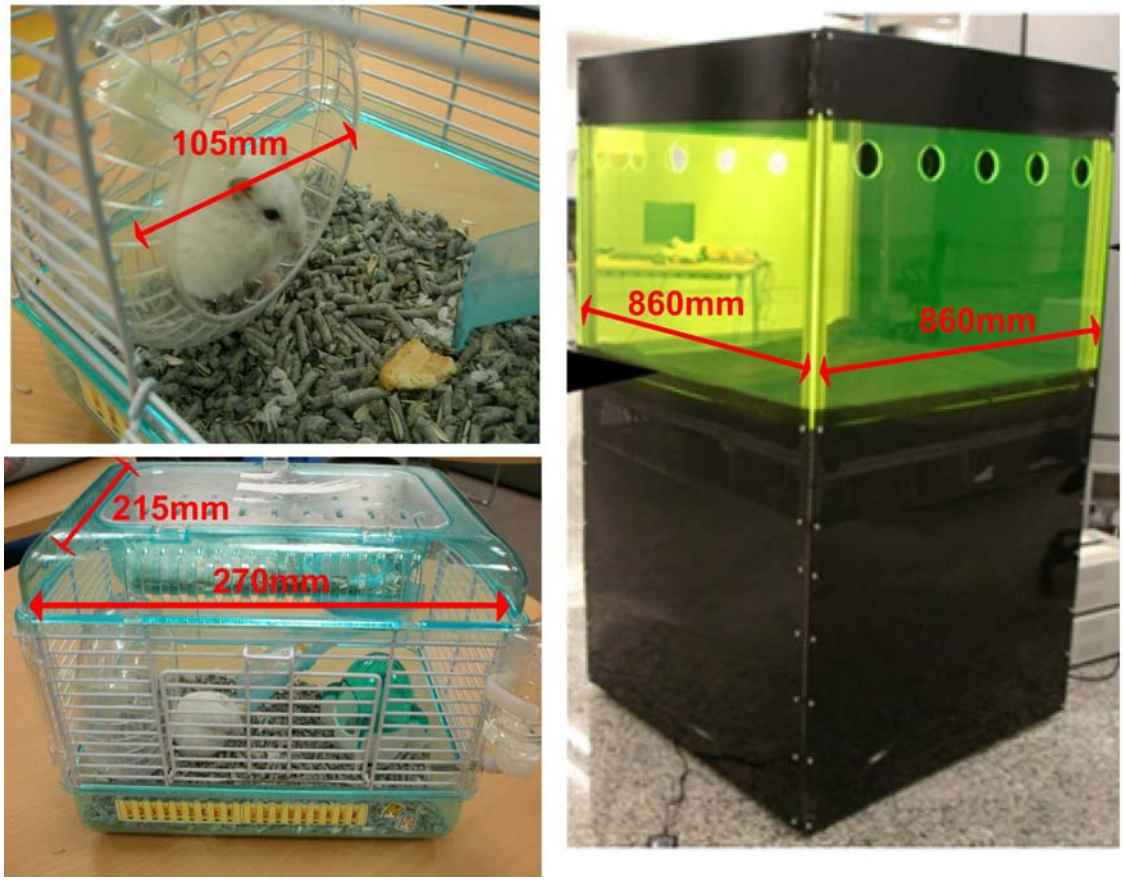

Figure 3.2: The running wheel, the hamster cage and the running space in Metazoa Ludens

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 (see Figure 3.2). 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 [69].

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 [70] as that is where they normally store their food resources [69]. 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 Internet. This forms the interface which enables the interaction between the hamsters and humans through the system.

3.6 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 is given next, followed by technical details of the system.

3.6.1 System Overview

In the real world within the big running space of the system, the 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 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 of the hamsters' movements on a mechanical 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. Taking readings from the system/game engine, the actuators will position themselves accordingly and change shape of the terrain accordingly to correspond to the virtual world's terrain.

The system/game engine is basically made up of 3 subsystems. Firstly, a camera subsystem which will take care of the camera tracking of the hamster. Secondly a hardware subsystem to send signals to the stepper motors that will in turn control the actuators and the three degrees of freedom mechanical robotic arm. Thirdly there is a software subsystem which processes the 3D real-time graphics of the virtual world as well as the interaction between the human and the hamster and and communicate to the hardware subsystem using Internet. The structure will house the camera subsystem as well as the hardware subsystem in two workstations named the camera server and system server (which holds part of the software subsystem) respectively while the equipment that the owner is using (be it a desktop at home or a laptop in a hotel room) holds the other part of the software 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.

3.6.2 Camera Subsystem

Setup for the Camera Subsystem

The Dragonfly camera (from Point Grey Research) which uses a Sony 1/3" progressive scan Charged Coupled Device (CCD) sensor which can detect both colour and black white images is used in Metazoa Ludens. It has a maximum resolution of 640x480 and has a maximum frame rate of 30 frames per second (FPS). It offers an IEEE1394 6-pin connection, which has a maximum data transfer rate of 400Mbits/s.

As seen from the given calculation below, the data transfer rate of 400Mbits/s is more than sufficient to transmit the images in real-time.

Resolution x (Bits per channel x No. of channels) x Framerate

= (640 x 480) x (8 x 3) x 30

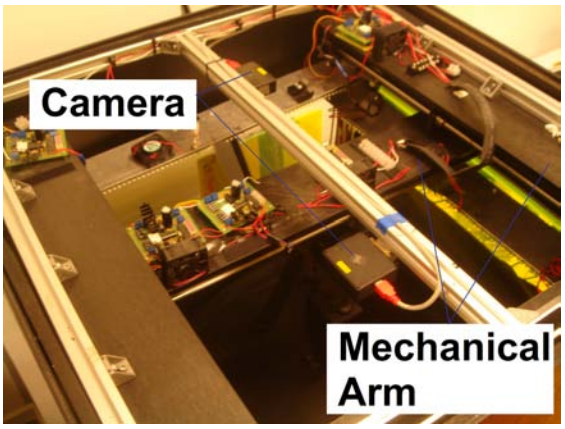

Figure 3.3: Placement of the camera above the mechanical arm

$$= 307200 \text{ x } 24 \text{ x } 30$$

$$= 211.184 \text{ Mbits per second} \tag{3.1}$$

Two Dragonfly cameras are used for Metazoa Ludens (to be explained in the later part of this chapter). Both cameras are connected to a PCI FireWire card on the computer. The software used to develop the hamster tracking system is Visual C++ on Microsoft's Visual Studio .NET 2003. The library used was OpenCV, an open-source computer vision library developed by Intel and runs on both Windows and Linux.

Using two cameras

To capture the movement of the hamsters their spatial coordinates must also be available at every point in time. The system will have to be acquiring an image of the running space area and identifying the hamsters constantly.

To capture the entire area of the running space the camera is placed above the running space. A possibility is to place it below the mechanical robotic arm however this is not feasible as it will obstruct the vertical part of the arm. Another possibility

is to place the camera on the robotic arm itself, however this means the camera will always be moving with the robotic arm and the algorithm to capture the whole running space becomes more complex. Hence a good solution is to place the camera above the robotic arm. However this may result in the obstruction of the camera's view from the mechanical robotic arm (see Figure 3.3). By observation the camera's view will only be blocked when the arm is just below the camera. To overcome this a second camera is placed at a location slightly off the first camera such that:

1. Distance between the cameras is greater than the width of the robotic arm.

2. Both cameras are able to capture the running space area.

The first condition ensures that only one camera at most may be blocked by the mechanic arm at any time. The second condition ensure that regardless of the position of the mechanic arm we will always be able to capture the entire running space using the cameras.

The system with the coordinates of the mechanical arm known, will take the x-coordinate of the mechanical arm to determine which camera to activate. When the x-coordinate of the mechanical arm coincides with the active camera, the other camera will be activated using the `CvCam` function of `OpenCV`. Basically `CvCam` works on a callback function which continuously acquires an image from the camera using its callback utility. The image acquired is stored in a global variable for easy access and used for object detection.

The program detects objects basically by using a homogenous colour as the background and any object whose colour is far from the background colour is picked up as the moving hamster. Black is chosen as the background colour (a black cloth is used to line the floor of the running space in this case) as this is a good contrast to the colour of hamsters which are mostly lighter in shade (like white or light brown). In addition black having a RGB value of (0,0,0) is a value which makes digital image manipulation using algebraic operations (like subtraction) easy.

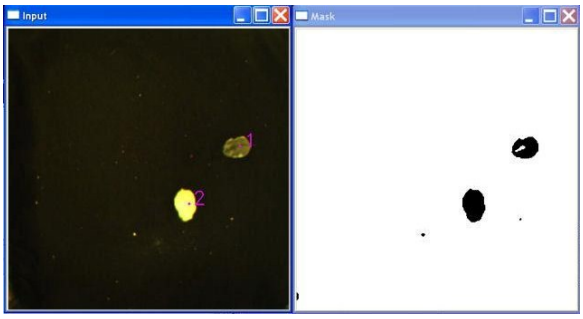

Figure 3.4: Comparison between the original image and the mask

For object detection, the camera subprogram is first initialised by taking ten images of the background from the camera. The colour of the background based on its RGB value per pixel is summed up as a total and averaged to give an average RGB value for the background. A standard deviation of the RGB value for the background is also obtained. These calculations are done using the `cvAvgSdv()` function in `OpenCV` and the values are stored for the entire duration of the program.

Using the average and the standard deviation obtained any images/frames obtained from the camera is then threshold against the background colour. This is similar to the blue-screen effect used in movies making where the background colour (in this case black) is subtracted from the image. When the input image is thresholded against the background colour, a one-channel mask is created. This mask is basically a binary image of the input image with each pixel capable of taking the value of either 1 or 0 (see Figure 3.4).

Let the average RGB value of the background be `RGBAve`, standard deviation of the background be `RGBSE` and the RGB value for the actual frame obtained be `RGBActual`. The thresholding is such that if `RGBActual` less `RGBAve` gives `RGBSE` then the background colour is being picked up and a value of 1 is stored in the corresponding pixel in the one-channel mask. If however the value is not within the range of `RGBSE` this is probably due to the presence of the hamster whose colour is being picked up (rather than the background colour). A value of 0 will then be stored in the mask. In this manner the mask is able to differentiate between the background and the hamsters, it then blocks out the unwanted areas (in this case,

the background colour) and leaving only the desired objects to be seen. As the mask is only a binary image, the individual-element processing is restricted to only a comparison function and a binary output function. This makes the amount of processing power required to compute each element much lower, and thus reduces computing time.

3.6.3 Hamster Coordinate Calculation

One problem is that the floor can sometimes get dirty, with food droppings and wood shavings appearing whilst shifting hamsters from the cage to the tank, or during the training of hamsters. These small objects are not desirable in the tracking process, so these small areas are filtered out first. A comparison of the region size versus a pre-defined limit is used to determine which objects should be ignored. This aims to reduce false detection within the system. After this filtering process, the remaining number of objects is then counted. The coordinates of each blob, except for blob 0, are obtained by averaging. This minimises calculations needed to find the exact centre of the object, whilst still providing coordinates that are definitively inside it. Further, the game engine does not require the coordinates of the hamster's exact centre to work at optimum level. Blob 0 is always the largest object in the image and is assumed to be the background. As the hamsters' dimensions are nowhere near the size of the background, the assumption is safe and can be discarded without any loss. Generally the hamsters are given subsequent number for blob for example blob 1 and blob 2 for the two hamsters identified (see Figure 3.5).

Once acquired, the image is then segmented to detect objects. This is usually done by thresholding against a certain colour value (black in this case), which either removes the background colour and converts into a binary image (as discussed previously). Two-dimension spatial coordinates of the objects located can then be calculated. For simplicity, the coordinates are calculated by averaging the maximum and minimum x- and y-values respectively, thus obtaining a value that is static if the object remains static and is always within the object. This value changes as the

Figure 3.5: Hamsters detected are labelled blobs 1 and 2

object (hamster) moves thereby giving the coordinates of the hamster within the game space.

The coordinates associated with each hamster are then transmitted to the server PC via TCP/IP, where they are combined with other data into a packet that it sends to the client. The orientation of the hamsters is determined by the game engine, which draws a vector based on the comparison between its current and previous coordinates (to be discussed in the later part of the chapter).

3.6.4 Potential Problems with Tracking - and their Solutions

There are a few important errors that can cause the module to fail to perform its function correctly:

1. Recognising an object as a hamster when it is not (False-positive)
2. Failure to recognise a hamster (False-negative)

Error 1, recognising a hamster when there is none, usually occurs when there is noise in the image. The filtering process removes small objects, but it does not detect objects that are close to or larger in size than the hamsters. This appears periodically from ghosting artefacts in the floor, see Figure 3.6 where blob 2 is

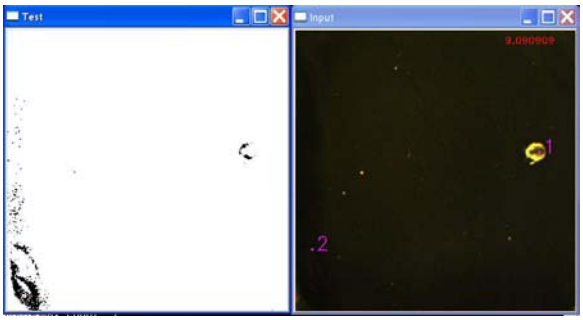

Figure 3.6: Error 1, recognising hamster's presence at location 1 and location 2 when there is no hamster at location 2

picked up as a hamster where there is none. During development, the tank is used to acclimatise hamsters to their environment, and food and wooden shavings can drop to the floor. The black cloth covering the floor traps the dirt and this sometimes creates ghosting effects on the image. To minimise this, the cloth has to be cleared of the debris regularly. Also, the minimum size of any object that can be picked up by the filter can be adjusted so that it will not pick up these artefacts. The deviation of the histogram matching algorithm is also modified to allow for less variation in the results before identification.

Error 2, failure to recognise a hamster, occurs when the current ambient lighting being different from that of the ambient lighting during calibration causing the hamster to cast reflective light (picked up by the camera) which make the hamster unrecognizable to the program. This is especially true when the hamster goes close to the side panels, which are translucent neon green in colour. This gives the hamsters a slight yellow tinge in their colour when they are close to the side panels. This is avoided by constructing a series of panels along the side to prevent the hamsters from venturing too near the sides. This also reduces the game arena and a smaller resolution can also be used for the image, which in turn requires less processing power.

3.6.5 Results Discussion

The performance of Camera Subsystem will be quantified and qualified in this section. The frame rate and the histogram matching accuracy will be presented.

Frame rate measurement

The frame rate for Metazoa Ludens is essential. It is calculated using the CPU clock to measure how long a single iteration of the system needs to complete. This value is converted to a time scale in seconds and its reciprocal is taken to obtain the frame rate. There were four tests carried out, one where the system is solely acquiring the image, one where the system is working with all functions enabled but without the hamster, one where the system is working with all functions enabled tracking one hamster, and one where the system is tracking two hamsters. The difference in these two values will provide a fairly accurate gauge of the frame rate of the image processing algorithm.

The values recorded were the CPU usage, the minimum frame rate and the average frame rate. The CPU usage was monitored visually using Windows Task Manager. The minimum frame rate was obtained by storing the lowest frame rate in memory, while the average frame rate was obtained by storing all the calculated values of the frame rate and averaging them at the end of the test. The tests were performed 20 times respectively, each time lasting 3 minutes. The system used was a Pentium-D 3.40GHz with 2GB of RAM and running on an Inno3D GeForce 7600 GS graphics card with 512MB DDR2 RAM.

Firstly, the program is run without the image processing functions. Just acquiring the image and cropping it to size required CPU usage of about 30 percent but not exceeding 35 percent. The minimum frame rate acquired was 22.13 FPS and the average frame rate acquired was 25.75 FPS. This is lower than the 30 FPS rating for the Dragonfly, but the reduced frame rate could be due to the processing

time needed for cropping the image. These values are still sufficient for the image acquisition function alone.

Secondly, the program is run with the image processing functions but without any object to track. The average CPU usage was about 90 percent but not exceeding 94 percent. The minimum frame rate returned was about 15.62 FPS and the average frame rate acquired was 17.22 FPS. There is a drop in the frame rate as expected, as the program is now calculating the mask, segmenting the image, labelling the region and transmitting data to the server.

Thirdly, the program is run with all functions and including the tracking for hamster. In this test, a hamster was used as the object to be tracked. The average CPU usage was observed to be about 92 percent but not exceeding 96 percent. The minimum frame rate returned was about 13.27 FPS and the average frame rate was 15.18 FPS. This drop in frame rate is also expected, as the program now has to identify another object, label it, calculate its histogram, match it with the histogram library and calculate its coordinates, all of which provide additional computing load to the system.

Lastly, the program is run with all functions and tracking two hamsters. The average CPU usage was observed to be about 94 percent but not exceeding 98 percent. The minimum frame rate was about 10.43 FPS and the average frame rate was 12.77 FPS. This average is above the limit of 12 FPS for the motion to be objectionably jerky [71].

In conclusion, the system is able to achieve an average of 12 FPS, which is suitable for real-time tracking, with an acceptable range for average CPU usage.

3.6.6 Hardware Subsystem

The hardware portion of the system (see Figure 3.7) consists of the server computer transmitting commands to the “Master” units, which then decode the commands

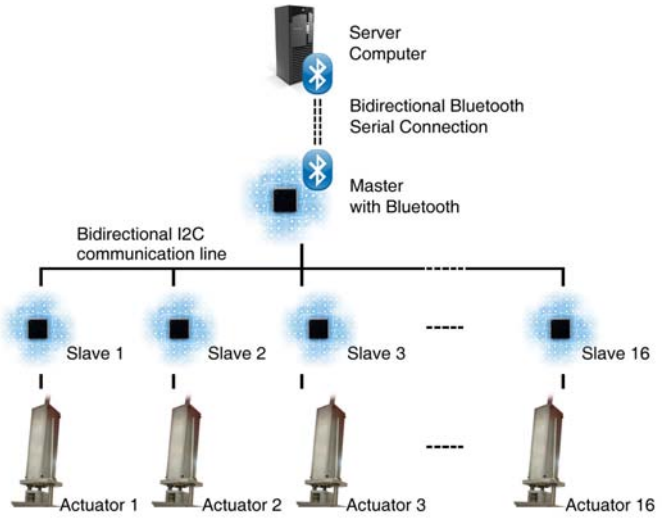

Figure 3.7: Hardware overview

and relay them out to the "Slave" units that are connected to 16 actuators (see Figure 3.8) used to mould 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.

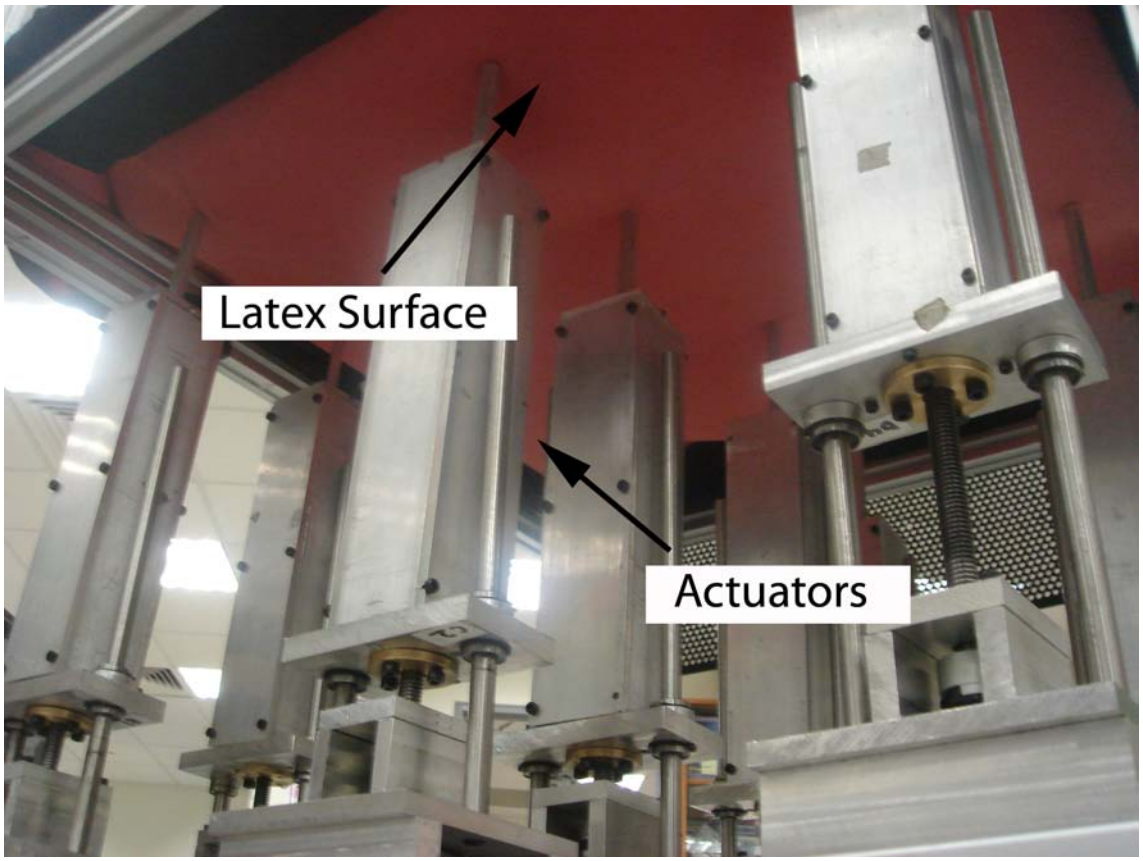

Figure 3.8: Actuators and latex surface

3.6.7 Bluetooth Communication

There are two main choices for the communication channel to the Master units, whether to use a wired or wireless transmission system.

For a wired system, either a Universal Serial Bus connection (USB) or an RS-232 Serial Connection can be used. USB is normally the best method to interface with PCB electronics as its voltage range of 5V is ideal for most Integrated Circuit (IC) chips commercially available. However, one limitation is that the cable length cannot be greater than five metres which greatly hinders development as the size of the physical hardware require for Metazoa Ludens is not inconsiderable.

From Figure 3.9, at a transmission rate of 19200 bits per second, the cable length is more than sufficient for our purposes. However, the RS-232 serial port uses a very

Baud Rate	Maximum Cable Length (ft)
19200	50
9600	500
4800	1000
2400	3000

Figure 3.9: RS232 cable length vs transmission rate

high voltage range of +- 25V which can damage the IC chips present in the system. Furthermore, many new computers do not ship with a RS-232 port attached, which can cause compatibility issues in the future.

From trials, the Bluetooth connection was very easy to establish and suitable for this project. In addition, the connection was still active even when line of sight (LOS) to the receiver was blocked by the metal shell of the tank. Finally, a test to compare the amount of data corruption in the system showed that of a hundred transmissions of the byte 0xf5 from the computer to the receiver, and then the received data was transmitted back to the computer again, all 100 times the computer received 0xf5.

The Bluetooth adaptor attached to the computer can be any of the commercially available brands, as long as it is capable of using SPP services (or Serial Port Profile). The Bluetooth chip on the hardware portion is the Promi-ESD from Initium.

First, the Promi-ESD is initialized and put into a scan-mode so that it is ready to accept transmission from nearby Bluetooth devices. Then the modem settings on both the server computer and the USART attached to the Promi-ESD are set to the same tranmission rate and handshaking options. Then, a link between the Bluetooth adaptor attached to the server and the Bluetooth unit on the receiver is established. The link is a virtual serial port connection which replicates all the available functions of a regular serial communications port on the computer, such as hardware handshaking.

Through the virtual serial port, data is written back and forth between the server

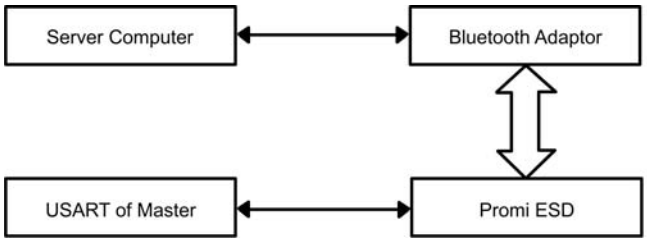

Figure 3.10: Communication from server computer to Master

computer and the PIC's USART in the same way as though they are connected by a wired connection (see Figure 3.10).

3.6.8 Hardware to hardware communication

So far, the system transmits a command from the server computer down to the Master unit. The next step would be to control the movements of the actuator units. However, this cannot be done solely by the Master as there are too many variables for it to control. Therefore, it has to be able to transmit the commands it has received from the server computer out to a number of Slave units, each of which control the actions of a single actuator unit.

For communications between hardware interrupt controllers, a common protocol used is called I2C. This setup uses two transmission lines to connect a master unit to 1 or more slave units, each implementing the I2C protocol. The master controls the clock line which synchronizes all the units together. All slaves can read and write to the master and vice versa, and there is a data collision detection system such that there is no chance of data corruption caused by two slaves transmitting to the master at the same time.

As there are only 7 bits available for coding the address of the slave, there is a maximum of 128 combinations. There are also 16 reserved addresses and as a result, the maximum number of units that can be chained together is 112, disregarding hardware considerations. If the address used is 0x02, then the Read/Write bit is 1,

Address Byte	Description
7 6	Slave unit address
5	
4 3	
2	
1 0	Read/Write bit

Figure 3.11: I2C Address byte Organisation

Figure 3.12: Master Unit

and the address is 1 (see Figure 3.11). As a result, the master is indicating that it wants to write data to the slave unit number 1. Each slave is hardcoded with a unique identification number.

The system is also very easy to extend, by simply connecting an additional slave unit to the two transmission lines. Only the master needs to be updated of this change for the system to work.

Master unit

The function of this unit (see Figure 3.12) is to receive commands from the server computer and distribute them to the other Slave units connected to it. Circuit diagram of the unit is given in Figure 3.13.

This unit comprises of the Promi-ESD, a programmable interrupt controller to handle all the required computational functions, LEDs for displaying output and

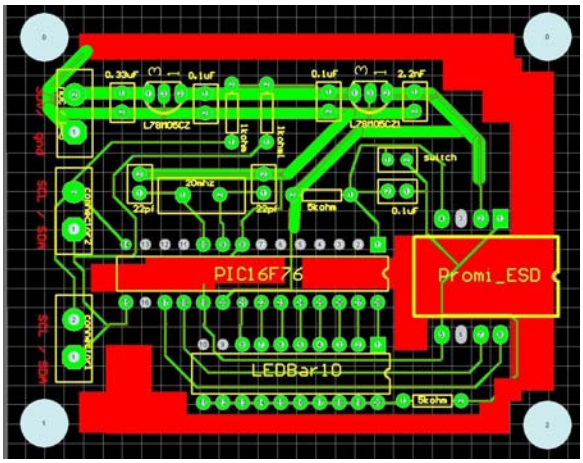

Figure 3.13: Master Unit

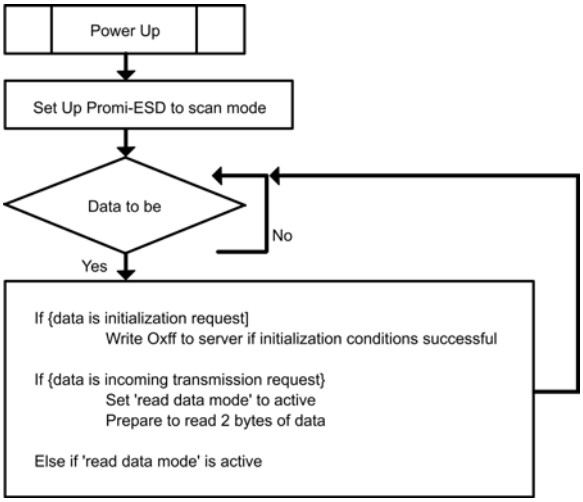

Figure 3.14: Master Program Sequence

data outputs to connect to the Slave units.

The system is based on a set of software handshaking instructions, so that when the computer sends an instruction to the Master, it will respond accordingly. This is important as both the computer and the Master are operating asynchronously and some sort of flow control is needed or transmission errors will occur.

On receiving the “read data mode” request, the Master will prepare to read in 2 more bytes (see Figure 3.14), the first is the address of the Slave to write to, and the 2nd is the data to be sent to that Slave unit.

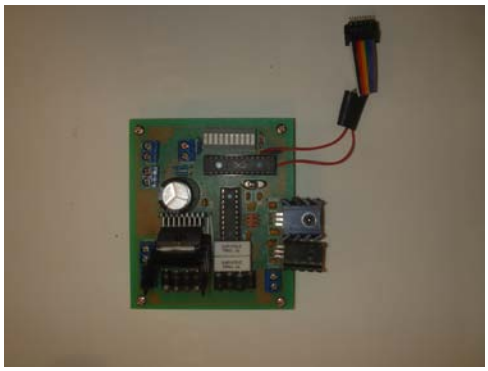

Figure 3.15: Slave Unit

Slave Unit

The function of the Slave (see Figure 3.15) is to interpret the digital commands issues from the server computer into the actual analog electrical signals required to cause the actuators to move. Circuit diagram of the unit is given in Figure 3.16.

The Slave consists of the PIC which regulates operation of the system and receives data from the Master, then it controls the stepper motor controller named L297 with clock-pulse signals generated by its output pins. The L297 interprets these electrical signals into the formate required for the control of a stepper motor and then transmits the required signals to the stepper motor driver named L298 which actually does the job of interfacing with the stepper motor and supplying the power required for the motor to function.

The actuator control mechanism is based on the concept of “desired height” and “current height”. The “current height” is the position that the actuator is physically at currently, whereas “desired height” is the height that we wish to set the actuator to. This is necessary because of the fact that things in the physical world have to take some time to respond to commands and cannot be set to a position immediately.

When the timer in the PIC overflows, it will generate an interrupt signal to order the PIC to run a piece of code which will toggle an output line to the L297. This line is the clock-pulse signal which controls the rate at which the stepper motor

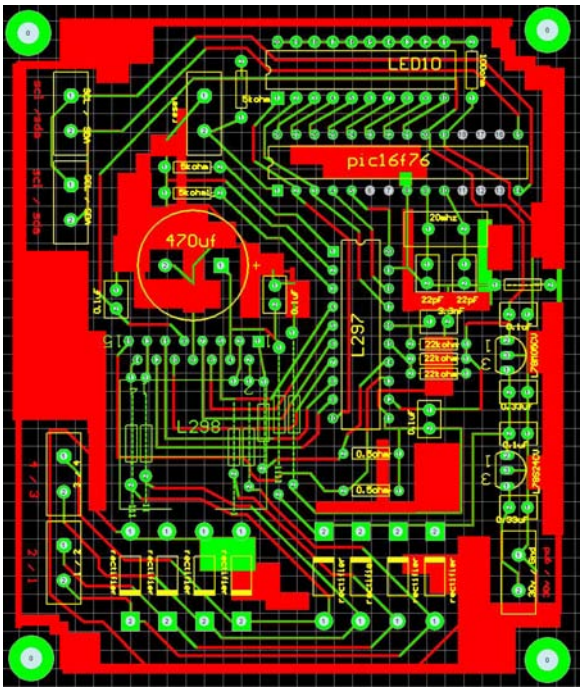

Figure 3.16: Slave Unit

rotates. The higher the frequency of the clock-pulse signal, the faster the motor will turn. Similarly based on the input of the "current height" of the actuator, should the "current height" reaches the maximum possible height for the actuator the PIC will generate an interrupt signal to stop the actuator from going any higher. This provides a simple feedback control system to prevent the actuator from going higher than it physically can.

3.6.9 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 Figure 3.8) in accordance to the virtual terrain of the gaming world in real time.

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.

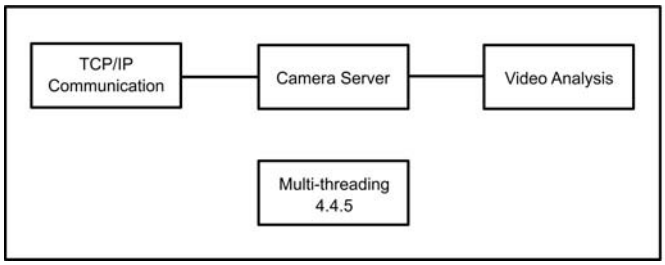

Figure 3.17: Camera Server Program Map

3.6.10 Software Subsystem

The software subsystem has three main functions: to provide a means to capture player input, display information to the player and be portable. It also must be capable in internet-based communications.

For the system, firstly there needs to be a method of displaying the virtual environment (consisting of the deformable floor, the human avatar and the hamster avatar and other miscellaneous objects). This virtual environment consists of many 3D objects, and there must be a collision management system to ensure that they do not overlap. Secondly a means of acquiring input from the human player is needed. A multi-threading system is required to keep all the individual modules functioning smoothly together. Finally, an internet transmission module is needed. These are described below.

3.6.11 Working with the Camera Subsystem

The camera subsystem (as discussed previously in this chapter) has two main functions: to analyze the video feed of the tank and extract the hamster's position; and to transmit this data over the internet to the software subsystem (see Figure 3.17).

The same base program is used in both subsystems. Multi-theading is used to keep the 2 modules working side-by-side without interference.

The system uses separate computers to run the Software Subsystem and the Camera Subsystem due to the fact that the camera tracking takes up a significant amount of system resources which can affect program performance. It is also more effective cost-wise to acquire two low-end computers that cumulatively have the same processing power as a single high-end computer.

3.6.12 Working with the Hardware Subsystem

The software subsystem must provide a point of contact between the hardware subsystem and the rest of the game which can be detailed under TCP/IP communications. It must link all the Masters (which link all the Slaves indirectly). To keep all the different processes operating smoothly, multi-threading is needed; and to generate the wave-form which defines the surface of the deformable terrain in the tank, a wave generator function is needed.

3.6.13 Software Platform

To provide an accurate virtual representation of the physical world, a graphics display component is needed. While 2D graphics can and have been used to good effect in many games, it is felt that they do not meet the expectations of a mixed-reality game.

With regards to development of 3D graphics, there are two main choices available: Microsoft's DirectX or OpenGL. Both are relatively equal in overall graphics performance, each with their pros and cons. But DirectX is already integrated with the Windows operating system and does not require cumbersome additional software which can cause incompatibility issues; especially given this project spans across areas other than graphics (such as acquiring user input, internet communications and hardware communication).

3.6.14 Multi-threading

Multi-threading is the process of running two or more concurrent loops in the game. This is an important part of the game engine as many processes are time-dependent, especially those that interact with external systems such as the data-transfer mechanism between two computers. If the graphics-rendering loop of the client takes too long to complete in a particularly complex scene, it could result in the data being transmitted to and from the servers to be transmitted late and so cause a "lag" from reality. For older PCs, the process of multi-threading is more akin to "time-slicing" where the CPU moves back and forth between the active threads.

Each process to be threaded will contain a loop description in its class header file. On starting the thread associated with this process, the loop will continue long until a command is issued to stop the thread, at which point the loop will freeze, but can still respond to commands.

It is important to place a Sleep command in the thread loop such that valuable processor activity can be shared out for the other functions of the program. If this is not then, then very short loops will repeat themselves many times more than necessary and cause the system to slow down unnecessarily.

3.6.15 Communication to hardware

The software subsystem needs a method by which to communicate with the electronic hardware that actually controls the operation of the motors and other systems in the tank. Most commonly available hardware transmission devices can be controlled through some form of serial port programming.

On initializing the serial port, it will send a byte to the recipient end and if the correct reply is received, the port will be set to 'connected', else it will continue to attempt to reinitialize. Once the thread is started, it will continue to exchange data with its counterpart until the thread is stopped.

3.6.16 Internet Communication

There are two main forms of transmission through the internet, TCP and UDP. The main difference between these is that TCP ensures reliable data transmission, whereas UDP has much less overhead per similar amount of data transmitted, resulting in faster transmissions.

The main issue against using TCP protocol in real-time applications is that it is not as fast as UDP, thus being unable to satisfy the needs of a real-time system. As a result, most time-sensitive applications in the world today use UDP as the transmission protocol. However, UDP brings with it many difficulties in implementation due to its light-weight nature and a lot of error-checking code must be present to ensure that the transmission process is smooth.

According to Bush and Ashworth [72], for a message length of up to 1000 bytes, the average transmission time to the recipient computer is almost identical. In terms of bandwidth, both protocols are also almost identical up for message lengths up to 1000 bytes.

As the message lengths in the program do not exceed 50 bytes per transmission which is well within the similar zone for both protocols and to simplify the overall code, the TCP implemention was selected.

On starting, the program will pause until a successful connection is made to the camera subsystem and the software subsystem. The program takes advantage of the robustness of TCP protocol to ensure 1-for-1 exchange of data with its connected computers such that there is no possibility for buffer overflows on either side. It does this by waiting on the read command until data is available from the other side, and then continuing with the loop. This might seem a waste of resources, but since this loop is implemented in a separate thread process, the main program is unaffected.

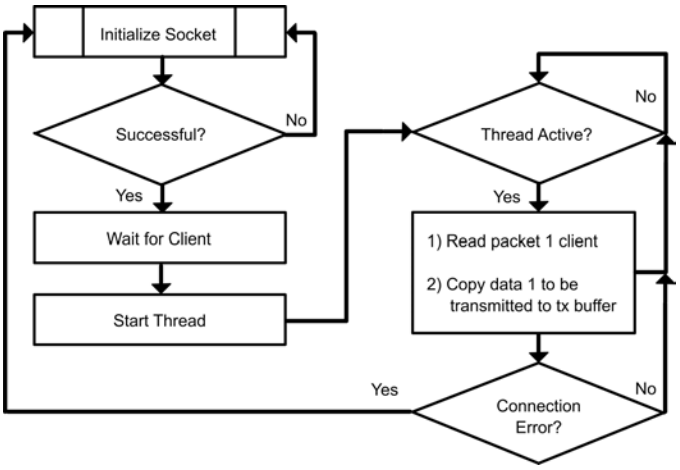

Figure 3.18: Server Program Transmission Cycle

The structure for the server program is similar to that of the client program, except that it waits for a connection on initialization and its loop process begins by reading data from the client and then returning data back (see Figure 3.18). Also, on the connection to the client getting interrupted, the server program will automatically reset itself and wait for another connection attempt from the server computer.

Hence for the system of Metazoa Ludens, the different parts of the system have been linked such that they are able to interface with each other remotely. In addition an environment has been created which maps physical objects in the real world to virtual objects the player can interact with these objects in the virtual environment and produce changes in the real world. the parts of the system. This will facilitate the bi-directional interaction goal of Metaozoa Ludens.

3.6.17 Working with the virtual environment

An overview of the virtual environment and objects of the game is given in Figure 3.19. Functionalities shown in Figure 3.19 will be encapsulated as objects for the game and rendered as 3D graphics onto the human user's screen (see Figure 3.20). Like most game engines, the basic functionalities like camera view, rendering of objects and such will be included.

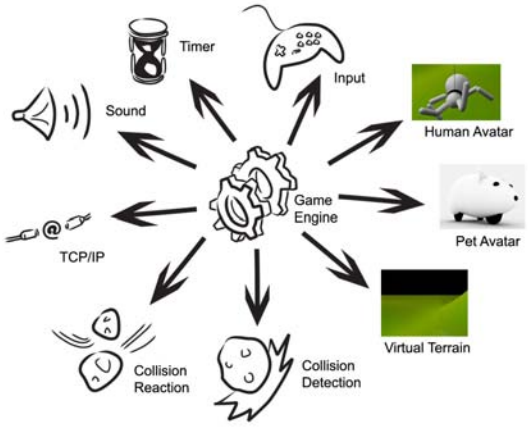

Figure 3.19: Game Subsystem Architecture

Figure 3.20: Virtual world game interface, showing Hamster avatar chasing human avatar

Human Avatar: The main character of the game is the human avatar which is 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 corresponds 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.

The Human avatar is always at a constant height above the terrain. This is done in the game engine by taking the current x-y coordinates of the human avatar and obtaining the z-coordinates of the virtual terrain at the same x-y coordinates.

A constant is then added to this z-coordinate which is then set to be the human avatar's z-coordinate. As such the human avatar will always be a constant height above the terrain regardless of the contour of the terrain.

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) whose control is by the hamster through the coordinates obtained from the camera. The pet avatar therefore moves as the hamster moves in the real world.

An issue which presents itself is the orientation of the pet avatar within the game. In order to give a more realistic representation of the pet avatar as the pet avatar moves, the direction it is facing should turn accordingly as well.

An algorithm named Direction approximation (DA) is used to approximate the direction the pet avatar is facing. DA does an approximation using a conservative assumption on the hamsters' movements: should the hamster move from point A to point B then it is assumed that this movement forms a vector, **AB**. This vector is a straight line from point A to point B in the direction from A to B. While this assumption may not be true all of the time however considering the nature of hamsters, chances of this assumption to be false are low. That is to say chances of a hamster moving from point A to point B without facing in the direction of vector **AB** is extremely low. Hence direction of vector **AB** is used to give the direction that the pet avatar is facing.

Nevertheless finding the direction of a vector may not be a straight forward operation. To meet up with the computational resource budget, this is simplified using approximation. At any position (xOld, yOld), the region around the hamster where it may move towards are divided into four quadrants. Should the new position of the hamster be (xNew, yNew), the quadrant which the hamster is in may be obtained using the four conditional statements given on the axis of Figure 3.21. By pre-setting the hamster's initial orientation during initialization, the new orientation may be obtained by adding , the angle of rotation with respect to the initial hamster

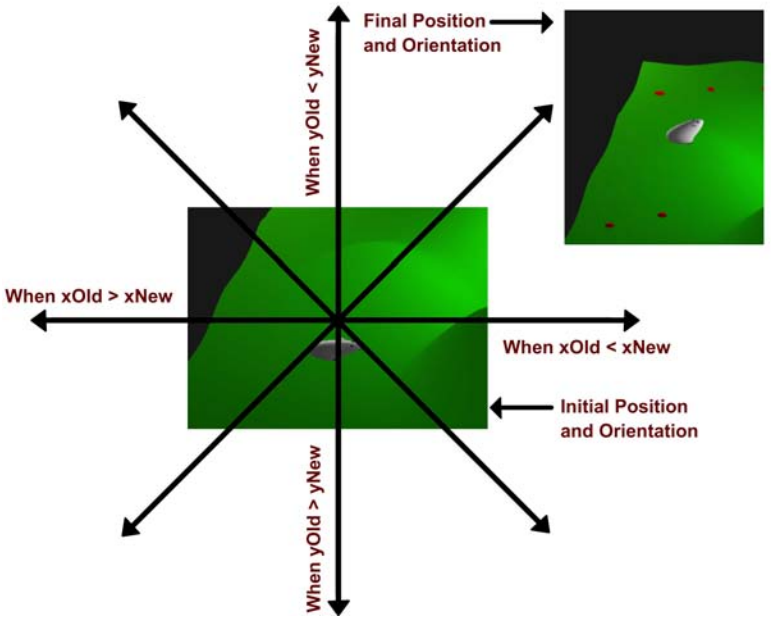

Figure 3.21: Direction approximation

orientation. For example, assuming that initial hamster orientation is 0 degrees facing the right (see Figure 3.21), should the hamster moves to any position in the top right corner quadrant as shown, the new orientation will be 45 degrees plus zero degrees regardless the hamster's current orientation. This however also depicts a loss in precision since should the orientation of the real hamster be 75 degrees, based on this algorithm it will still be shown only as 45 degrees in the virtual world. Nevertheless in the virtual world where the precise angle of rotation is not essential, this good enough approximation seems appropriate while trying to reduce computational resources.

Two test cases are carried out while noting down the minimum and maximum fps in each case.

In Case 1, without Internet connection where the game engine is running on its own, the minimum and maximum fps gives a range of (40, 42). This is an acceptable frame rate and is able to present the game in real-time.

In Case 2, with Internet connection to the real structure, the fps range dropped to (24, 26), visually game play remain acceptable and the game runs on real-time.

DA only need the virtual hamster's initial orientation preset by the programmer, current virtual hamster orientation need not be stored. While DA gives an approximation (and not precise values) however DA's approximation is good enough for game play and it gives a high fps suitable for game play.

Virtual Terrain:

To represent the deformable floor of the tank in the virtual environment, a surface must be create that has the following attributes

1) Deformed at the 12 points where the actuators are fixed to the latex floor

2) Smooth curve such that the surface looks realistic, instead of straight lines

3) Fairly computationally effective to create and modify

One idea to implement this was to first obtain a set of fixed points in the environment (the 12 actuator heights) and then use interpolation to connect all of these points to generate a smooth surface. However, to get a smooth surface, a large number of fixed points are needed. This will result in a very high degree polynomial function and will cause a noticeable lag in the program performance every time the surface is recalculated to account for terrain deformation. This recalculation has to be done every time an actuator moves, and so is unavoidable if this method is used.

Another solution was to pre-calculate an array with the values of the half cosine function, and add this function to each point represented by the actuators, modified by the actual height of the actuator at that point. Due to the 4x3 formation of the actuators, as well as the square-shaped area of the tank, the cosine image will have to be skewed to a ellipse before usage. This will result in Figure 3.22 where each ellipses of varying sizes are used to represent an area of the surface for molding the

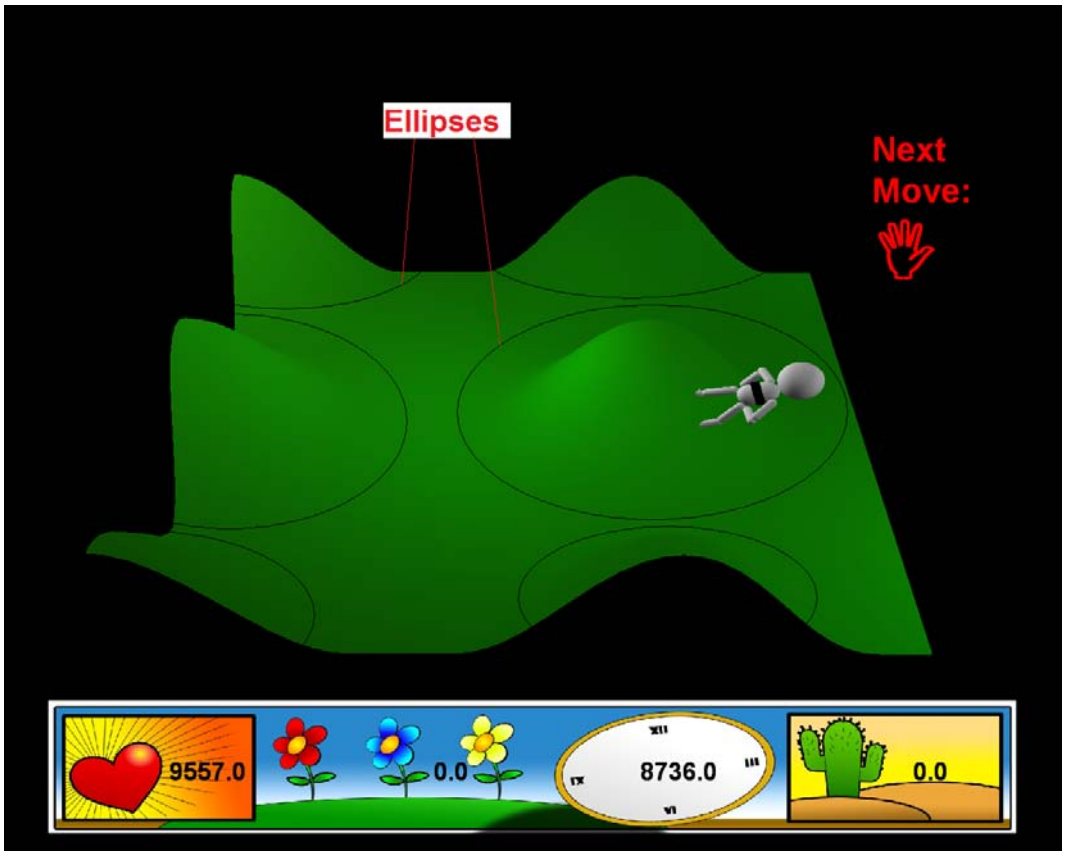

Figure 3.22: Ellipses of varying sizes are used to represent an area of the surface for molding the virtual terrain of changing surface contour. Note that the ellipses are added in this case to illustrate their usage by the algorithm

virtual terrain of changing surface contour. The ellipses at the side represent the places where the latex sheet joins the sides of the tank.

Using quadratic addition, the combined output of all the functions added together produced a smoothly curving surface which was usable in real-time.

Collision Handling:

In order to create a virtual 3D environment, it is necessary to address the issue of collision handling. This is the process whereby the program detects if the borders of 2 or more objects are going to pass through each other, and to decide whether the objects will bounce off each other, stick together, or just pass through as though there is no object there.

The physical parameters of the tank, the hamster and the human avatar can be captured from video camera and since they would never pass through each other in reality and this game is aimed to be an accurate simulation of that reality, they would not collide in the simulation as well. However, a system of collision detection is still necessary as this project aims to provide more than merely copying from the physical environment. Other virtual objects can be generated and exist solely within the computer and serve to make the game more interesting for the player and these objects require collision detection to be of use in the game.

Most 3D collision systems work by defining a bounding box for each object in the environment. This bounding box represents the volume that the object has, and if another object enters this space, a collision between the 2 objects is detected.

The more faces (for 3D bounding boxes) or sides (for 2D bounding boxes), the more complex code required to accurately distinguish between two intersection objects. It is important to keep the number of calculations required per object in the environment low such that the program can run in real-time.

The bounding-boxes of the hamsters and the human avatar are represented as spheres. The objects that they map to in the real world (hamster and bait) have the same rough physical dimensions as a sphere and so the loss in precision is negligible.

Figure 3.23 details the process of collision handling and how it is carried out in the game. All objects are represented as spheres, and as such, only two pieces of data need to be stored per object: its current position and its radius. The square of the magnitude of the distance between two objects is obtained by getting the dot product of the difference between their position vectors. As the game environment is sparsely populated, it is still computationally effective to do a second order search (that is an N^2 search) for collisions against all objects, as opposed to maintaining one of the more complex trees for handling 3D object collisions.

Movement of objects in computer programs is done in discrete steps, having the object jump forward a small distance at a time, instead of continuous movement in

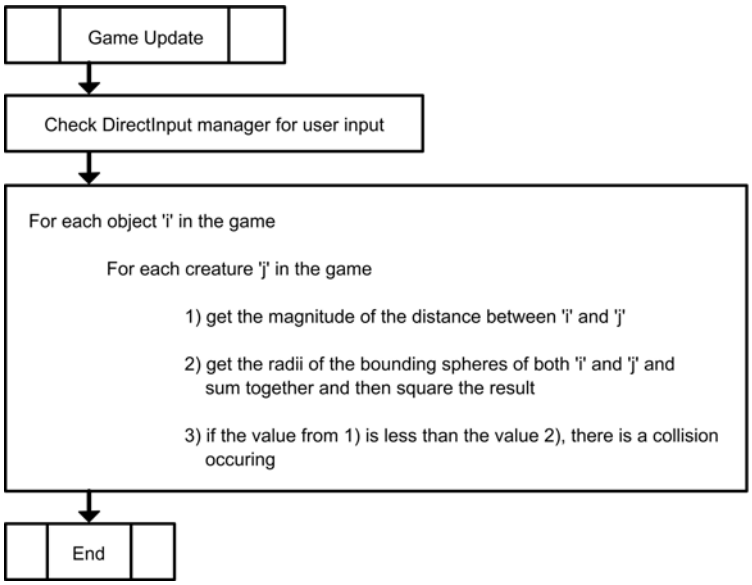

Figure 3.23: Collision Detection

as the physical world. This implies that if the discrete 'jump' an object makes in 1 frame is greater than the size of an object in its path, it is possible that the moving object might jump through the obstructing object completely and have no collision reported.

For a more realistic system, the case whereby both objects are moving during the frame should also be considered. However, to consider the case of two moving spheres, then their bounding volumes have to be represented as cylinders to illustrate the path swept out by their motion vectors and the collision calculations now have to consider the case of two cylindrical bounding volumes which is vastly more complex as a cylinder is an asymmetrical surface and is harder to test for as compared to a sphere.

However, the rate at which the human and hamster avatars move are tied to the actual objects in the real world, and so there is an upper-limit as to how fast they can move. Also, preliminary tests have shown the current game frame-rate to be at 30 per second. Neither the hamster, nor the mechanical arm can move greater than their own diameter in 1/30 of a second as this would require a speed of over 9 metres per second and is not physically possible for either.

As a result, it is sufficient to consider the case where both objects are assumed to be static at the beginning of each frame and this will not result in a situation where false negatives are reported.

Spawn Flowers:

In the game, flowers are spawned randomly along the terrain which the human avatar may collect. Each collection will cause the pet avatar to grow in size this implies it will be harder for the human avatar to move within the virtual world without colliding into the pet avatar.

The flowers are spawned using a randomized number generator, generating a random number, i, between 0 and 1000. A range is set such that should i fall within the range, a flower will be generated within that game loop; the smaller the range the lesser the chance that a flower will be generated within the loop. Location of the flower again is randomized by generating a random number for both its x and y coordinates. Like the pet avatar, z coordinates of the flowers are obtained from the virtual terrain such that the flowers always rest on the virtual terrain regardless of its surface contour.

3.7 User Experience and Gameplay

We now will describe a typical usage scenario of our system (see Figure 3.1).

When the hamsters leave their cages and go into the Metazoa Ludens' structure it signifies the start of the game play (see the picture on the right in the second row of Figure 3.1). The pet owner gets ready in front of his computer (either at home with the pets or remotely over the Internet) with a virtual world on his screen. The heart (see Figure 3.24) denotes the life points left for the players, the flowers denote the number of flowers the user has collected. The timer denotes the time left and the final number on the far bottom right side of screen denotes the score of the user

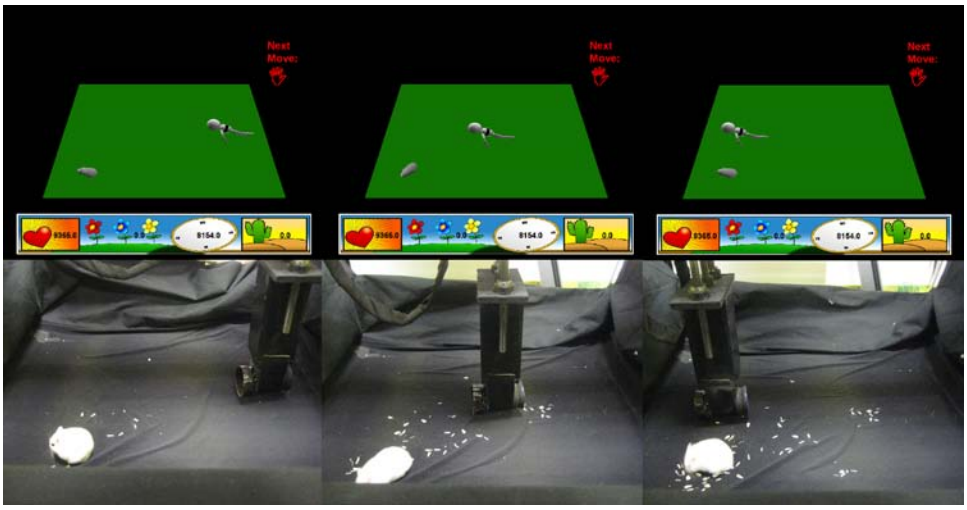

Figure 3.24: Human avatar position causes correspondingly the change of position of the mechanical arm. Note again the virtual hamster position corresponds to the physical live hamster position

so far. The human avatar is the avatar in the game which the user is controlling. The Next Move on the top right corner denotes the next move of the user.

As the user moves the human avatar (using the keyboard) in the virtual world, correspondingly the mechanical arm with the attractor in real physical world moves as well (see Figure 3.24).

The basic game concept behind Metazoa Ludens game is a predator and prey chase game, however roles are reversed in the sense that the bigger human is now being chased by the physically small hamsters in the virtual world (pet avatar chases after human avatar). A general strategy of the pet owner is to try his best to keep moving his human avatar so as not to be caught up by the pet avatar (hamster), which will then deplete the human avatar's health points. On the other hand the human avatar may go around collecting flowers (red roses) to increase points and health points (see Figure 3.25).

But as more of the flowers are collected the pet avatar will grow in size in the virtual world (see Figure 3.26). This makes it even harder for the human avatar to avoid colliding into the pet avatar.

Figure 3.25: Human avatar goes around collecting flowers

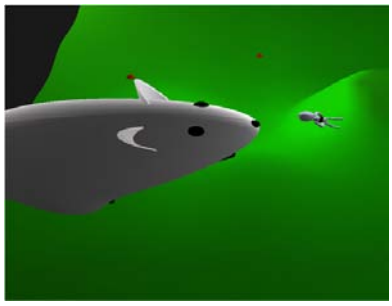

Figure 3.26: Pet avatar grows bigger

Should the hamster runs through the attractor/tunnel in real physical world, the pet avatar and human avatar will collide in the virtual world (shown in Figure 3.27) the human avatar will lose life points in the game.

Throughout the game the virtual terrain will change randomly to enhance the game experience. As the virtual terrain begins changing its contour, in the real world the elastic surface of the structure will begin changing its contour at the same

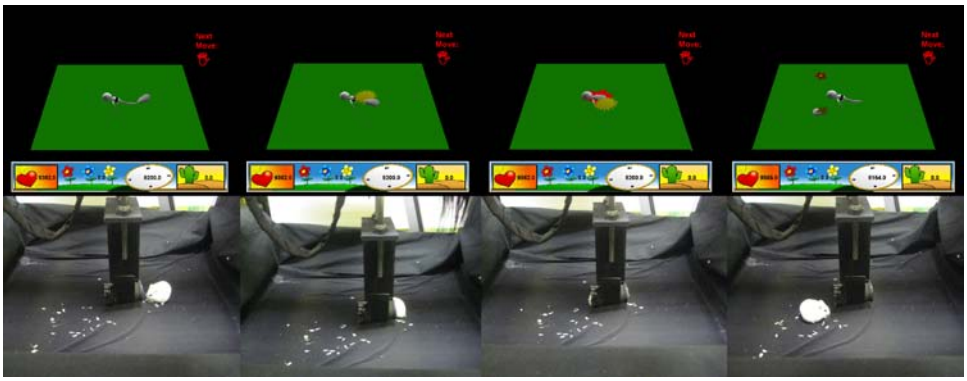

Figure 3.27: Hamster runs through the tunnel

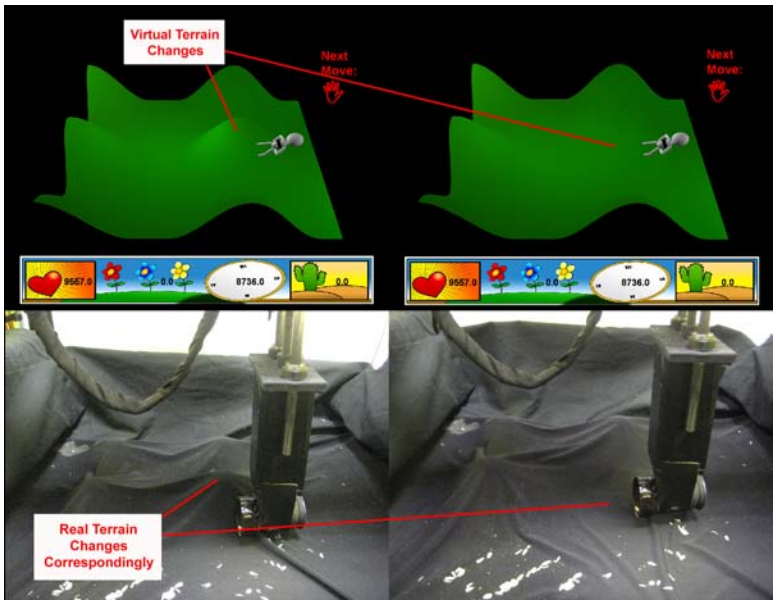

Figure 3.28: Virtual terrain changes and real terrain changes correspondingly

time. This is made possible by the actuators underneath the elastic surface (in the real world). By changing their heights, the actuators increase the concavity and convexity of the elastic surface's curvature. At the same time these changes correspond to the changes happening in the virtual terrain in the virtual world. This thus molds the elastic surface of the structure which the hamster runs on while keeping the mapping between the real and the virtual world (see Figure 3.28).

The game ends when the life points of the human avatar run out or when the timer runs out of time. Scores of the human avatar are then recorded to show the result of the human/hamster performance for the game. With the game system as described and explained we will next move on to discuss the user studies done on Metazoa Ludens and the generalised framework thus derived.

Chapter 4

Metazoa Ludens: Experimental Results

This chapter provides the results of studies done on the four hypotheses through the hamsters' health via BCS, method of Duncan on the hamsters, human user studies based on the Flow model [2] and studies done on empathy media. A generalised framework for human-animal interaction system is given based on the literature surveyed previously.

4.1 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 lifespans, 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 such as obtaining body weights and temperatures which can be time-consuming and tedious, BCS techniques are more practical and rapid [24].

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

- 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 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 [69].

Procedure All hamsters had their BCS taken at the start of the first 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 flash

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 [24].

For six weeks, the metabolizable energy requirement (MER) [42] 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.

Twenty out of forty of the hamsters were allowed to play Metazoa Ludens for an hour each on every weekday for the period of six weeks. At the end of the sixth week their mean BCSs were taken again. The other twenty hamsters were used as a control and were allowed to go into the Metazoa Ludens structure for an hour each on every weekday for the period of six weeks but without any game play.

The use of twenty hamsters for each group allowed us to take accurate averages of our data, and was sufficient to account for any anomalies that may have arisen in the data due to hamster variations. The control group was allowed to go into the Metozoa Ludens structure - but without gameplay - in order to allow them the same exposure to the outside world as their counterparts, alongside the same opportunity to exercise. This ensured a fair test.

Statistical Analysis To compare ordinal data (discrete scoring of BCS) between two time points (BCS scoring in the first week and the sixth week), 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 [73]. All statistical tests were two-tailed, with statistical significance at 0.05. Data are expressed as means unless otherwise specified.

Results Of the 44 hamster owners and their pet hamsters screened, 40 (about

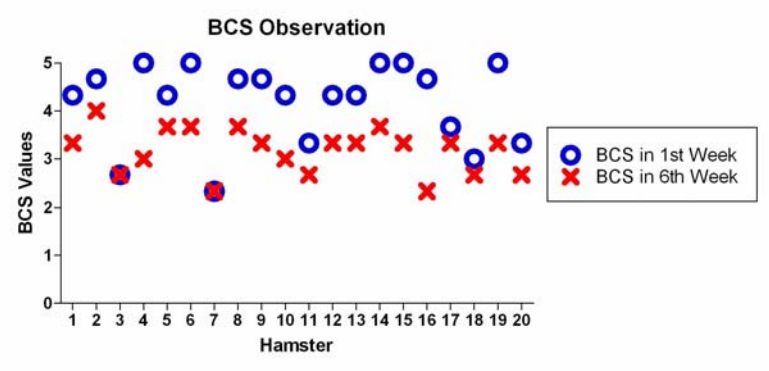

Figure 4.1: BCS results of the first group of hamsters over 6 weeks

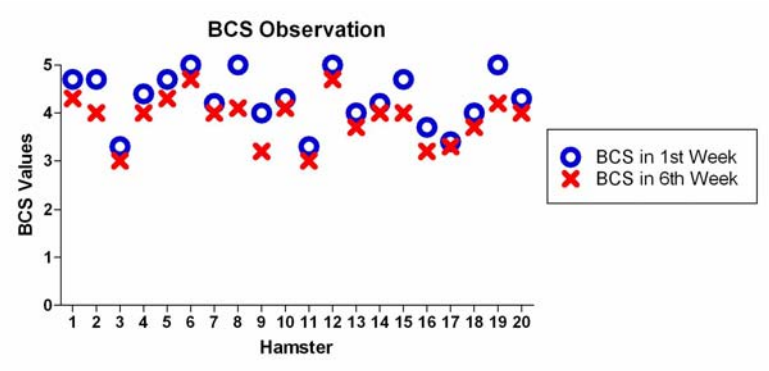

Figure 4.2: BCS results of the second group of hamsters over 6 weeks

90%) subjects were enrolled in the study (3 were not interested, 1 did not return for follow-up). The final study group consisted of 18 female hamsters and 22 male hamsters. Both groups of hamsters consist of 9 female hamsters and 11 male hamsters. The results for the first group are shown in Figure 4.1. The results for the second (control) group are shown in Figure 4.2.

By using Wilcoxon signed-rank test for the first group, Metazoa Ludens was found to be able to change the BCS of the subject hamsters over the study period ($z = -3.8230$, $p = 0.0006$, Wilcoxon signed-rank test). Further statistical analysis of the mean BCS of the first group of 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 ($z = -1.4154$, $p = 0.1586$, Wilcoxon signed-rank test), which is the optimal BCS score for hamsters.

By using Wilcoxon signed-rank test for the second group (control), running in the Metazoa Ludens structure without game play was found to be able to change the BCS of the subject hamsters over the study period ($z = -3.8667$, $p = 0.0006$, Wilcoxon signed-rank test). Further statistical analysis of the mean BCS of the second group of 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 4 ($z = -1.4233$, $p = 0.1586$, Wilcoxon signed-rank test).

Hence it can be concluded that after 6 weeks of playing with Metazoa Ludens, the hamsters in the first group are getting healthier and their body condition tends to optimal of 3. While on the other hand the hamsters in the second group (control) despite getting healthier (this is probably due to running in the bigger space given in Metazoa Ludens relative to their cages) their BCS is only tending towards 4 instead of 3. This thus shows that our first hypothesis is correct as well as fulfilling our objective of having Metazoa Ludens to give health benefits to the pet hamsters.

4.2 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 as a test of the second hypothesis. Study 2 was carried out after Study 1 as both studies are rather similar and we did not want an interference of results. In this study the method of Duncan [7] 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 remained 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 will be left to explore the structure without the game play for about 1.5 hours. This is to act as a control against the hamster coming into the structure out of inquisitiveness rather than a desire to play the game.

For the first group once 1.5 hours is up, a whistle will be blown to signify the start of the Metazoa Ludens game. The hamster may 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 will readily return to the safety of their homes (or run for cover) should they feel uncomfortable even if they are running in a big field [24]. 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.

For the second group (control) once 1.5 hours is up, a whistle will be blown but without the start of the Metazoa Ludens game. The hamster may chose to stay or leave the structure through the tunnel at this point of time. 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 four 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 fourth week. Based on the design of the pet interface which is towards the preference of the hamsters (see Scenario 3) we hypothesized that after four weeks the mean number of times for the hamsters to choose to play Metazoa Ludens will increase, that is the hamsters' preference for Metazoa Ludens will 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 for the first group are given in Figure 4.3. By using the single-tailed Wilcoxon signed-rank test, it was shown that the mean number of times

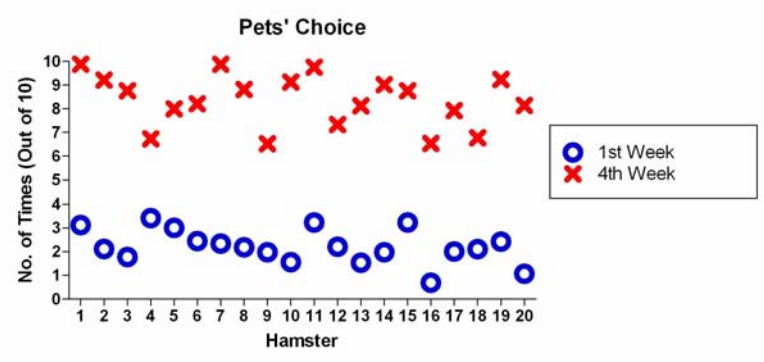

Figure 4.3: Results of Pets' Choice for first group over 4 weeks

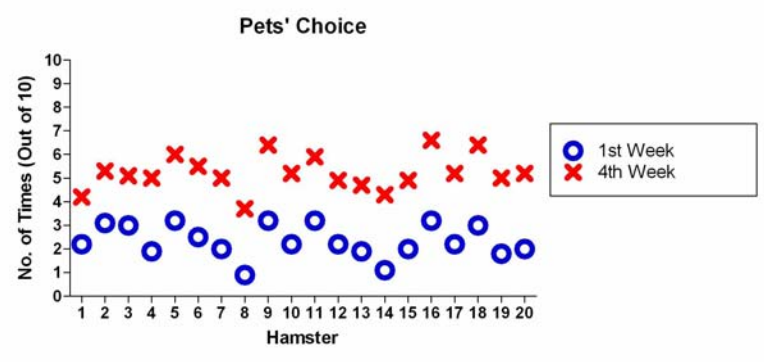

Figure 4.4: Results of Pets' Choice for second group over 4 weeks

taken for the hamsters to play the game per day increased over the study period ($z = 3.9199$, p more than 1.0000, Wilcoxon signed-rank test). 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 ($z = 0.7467$, $p = 0.9468$, Wilcoxon signed-rank test), that is 60% increment.

The results for the second group (control) are given in Figure 4.4. By using the single-tailed Wilcoxon signed-rank test, it was shown that the mean number of times taken for the hamsters to stay in the structure without game play per day increased over the study period ($z = 3.8236$, p more than 1.0000, Wilcoxon signed-rank test). With the two-tailed Wilcoxon signed-rank test it was shown that this increase was by 3 times per day out of the 10 possible given chances ($z = 0.8235$, $p = 0.9431$, Wilcoxon signed-rank test), that is 30% increment.

As it is shown that the hamsters in the first group increasingly choose to play Metazoa Ludens during the study period (increment of 60%) as contrast to the second group (whose increment is only 30%), we conclude that the hamsters have a positive desire to play Metazoa Ludens. This therefore shows that our second hypothesis is correct as well as fulfilling our objective of giving the hamsters a choice for game play.

4.3 Study 3 - Users' enjoyment based on Flow

For the users, a user survey was carried out to evaluate Metazoa Ludens system as a game. Game flow of the system was then broken down using features as described by Csikszentmihalyi's Flow theory [2] to evaluate the users' enjoyment of the game.

Csikszentmihalyi's Flow theory allows the analyst to determine an accurate reflection of the happiness of users engaged in a specific activity, as it allows for that activity to been seen as being experienced as a potential state of 'flow' as opposed to a passively experienced static event. As defined by Csikszentmihalyi, 'flow' is: 'the state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it.' [2]. Such defined, achieving a state of flow is seen to be the ultimate aim of human activity. But it is particularly important in the act of gaming and imaginative play such as Metozoa Ludens and hence our analysis, since we are aiming to develop a game that will protract - along the lines of Empathetic Media - a state of emotional fulfillment, immersion and happiness amongst users Flow theory therefore provides the most useful analytic model for evaluating our aims.

Metazoa Ludens game flow is 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 players' 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 their 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 is 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.
- **Human-animal Interaction:** The game should support interaction with the pet as well as make the player feel closer to the hamster.

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 gives the questions and corresponding criteria and elements in the Flow model

Subjects Subjects were recruited from a local hamster- lover community. There were 40 subjects randomly selected with an average age of 25.4 years old. Gender was 55 percent male and 45 percent female. All subjects completed written informed consents before inclusion in the study.

Procedure The survey was conducted on 20 of the subjects (all who were first time users of Metazoa Ludens) right after game play. The rest of the 20 subjects were used in a control group whereby they play Metazoa Ludens for the first time but without knowing that they are actually playing the game against a real live hamster. The survey was also conducted right after game play. Data collected from the survey are expressed mainly as means, unless otherwise specified.

Results Results of the survey for the first group are given at Table 4.2.

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) Does the game skills needed match yours?
	4) Do you think the game provide 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 at 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?
	11) Are intermediate game goals clear and presented at appropriate times?
Feedback	12) Do you have a clear picture of your progress to the game goals at any point of time?
	13) Does the game give you immediate feedback of your actions?
	14) Do you always know your health points and time remaining?
Connection	15) During gameplay are you less aware of what is happening physically around you?
	16) Are you aware of the passing time during gameplay?
	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 gameplay?
	21) Do you feel more connected to the pets after gameplay?

Table 4.1: User Evaluation Questions based on Flow model

Results of the survey for the second (control) group are given a Table 4.3.

Looking at the results obtained as a whole, overall for the first group, of all elements explored with this survey, most of them performed positively, with more than 50 percent selecting the favorable choice (choice of 'Fairly' to 'Yes, very'). Nevertheless it is noted that the element Social Interaction did not score as well as the rest. For the second group, each of the criterion performed slightly lesser than the first group except for the criterion on human-animal interaction where all the subjects in the group responded poorly, thinking that the human-animal interaction refers to their interaction with the pet avatar in the game.

Questions 1 to 14, looking at Table 4.2 almost all from the first group selected the favorable choice (choice of 'Fairly' to 'Yes, very') and a very high percentage of the users selected 'Yes, very'. Only for Questions 9, 11 and 13 do we have 5% of users selecting 'Not really' and none of the users chose 'No'. For the second group we gotten very similar results as well. Looking at Table 4.3 almost all selected the favorable choice (choice of 'Fairly' to 'Yes, very') and a very high percentage of the users selected 'Yes, very'. Up to 10% of users selecting 'Not really' for some of the questions but none of the users chose 'No'. As Questions 1 to 14 are dealing with the state of 'Flow' based on the system (in this case the virtual world which the users were interacting with), this shows that the virtual world part of the system is successful as a system that could induce 'Flow' in the users.

Questions 15, 16 and 17, which concerned the state of 'Connection', namely, does the user feel lost in the game and lose track of time, were answered mostly in the positive by both groups, with a slight bias towards those in the first group, and the only negative response being in the second group. Whilst 80% of second-group users answered 'yes, very' to whether they felt lost in the game; it was a full 95% of first-group users who felt very immersed in gameplay. This further strengthens the case that playing with a real hamster has a positive effect on users, as well as delivering more satisfying and emotionally-fulfilling gameplay.

Questions 18 and 19 which were for Social Interaction, the majority of the first

group 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 are new to the game and having 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 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.

Questions 20 and 21 which is concerned with human-animal interaction, the results of the survey are promising. As mentioned, in the first group - those who aware they were playing with a pet - 85% responded positively when asked if during gameplay itself they were aware of playing with a hamster. 100% of these users said that they felt more connected with hamsters afer gameplay. In contrast, only 15% of the control group claimed to be aware of playing with a hamster, and resultantly, only 5% felt more connected with their pets after gameplay. This shows a clear connection: those aware of playing with a pet feel more connected and hence 'flow' afterwards; whereas those not aware of playing with a pet, don't. Through playing the game, users who are aware of playing with the pet became more connected to their pets which is part of 'flow.

In addition, based on the rest of the results in the survey given, it can be concluded that generally the goals (from Flow metrics) are effectively implemented since in general the human players from the first group feel the state of 'flow'.

4.4 Study 4 - Studying empathy

For the Metazoa Ludens as a means to convey Empathetic Media, a user survey was carried out to evaluate the game as Empathetic Media. Questions were asked

based on hypotheses (to be discussed) derived to evaluate using Metazoa Ludens to interact with the hamsters as a means of conveying Empathetic Media.

The hypotheses themselves (see below) are clear and straight forward on their own, and they are derived for the purpose of uncovering the effectiveness of Metazoa Ludens as Empathetic Media. The hypotheses and their corresponding user study questions are given in Table 4.4.

Subjects Subjects used were the same subjects used in Study 3 with all experimental conditions remained unchanged.

Procedure Procedure used were the same as in Study 3. The survey was in actuality carried out directly after user completed the survey for Study 3.

Results Results of the survey for the first group are given at Table 4.5. While results of the survey for the second group are given at Table 4.6.

Qn	Options				
	Yes, very	Yes	Fairly	Not really	No
1	75.00%	25.00%	0.00%	0.00%	0.00%
2	70.00%	10.00%	20.00%	0.00%	0.00%
3	65.00%	20.00%	15.00%	0.00%	0.00%
4	70.00%	30.00%	0.00%	0.00%	0.00%
5	60.00%	20.00%	20.00%	0.00%	0.00%
6	95.00%	5.00%	0.00%	0.00%	0.00%
7	85.00%	15.00%	0.00%	0.00%	0.00%
8	95.00%	5.00%	0.00%	0.00%	0.00%
9	65.00%	20.00%	10.00%	5.00%	0.00%
10	95.00%	5.00%	0.00%	0.00%	0.00%
11	70.00%	5.00%	20.00%	5.00%	0.00%
12	65.00%	15.00%	20.00%	0.00%	0.00%
13	65.00%	15.00%	15.00%	5.00%	0.00%
14	85.00%	5.00%	10.00%	0.00%	0.00%
15	95.00%	5.00%	0.00%	0.00%	0.00%
16	60.00%	40.00%	0.00%	0.00%	0.00%
17	40.00%	50.00%	10.00%	0.00%	0.00%
18	15.00%	70.00%	10.00%	5.00%	0.00%
19	15.00%	55.00%	20.00%	10.00%	0.00%
20	60.00%	10.00%	15.00%	15.00%	0.00%
21	65.00%	30.00%	5.00%	0.00%	0.00%

Table 4.2: Results of Survey for First Group for Study 3

Qn	Options				
	Yes, very	Yes	Fairly	Not really	No
1	65.00%	20.00%	10.00%	5.00%	0.00%
2	70.00%	15.00%	10.00%	5.00%	0.00%
3	60.00%	20.00%	15.00%	5.00%	0.00%
4	65.00%	30.00%	5.00%	0.00%	0.00%
5	55.00%	20.00%	15.00%	10.00%	0.00%
6	90.00%	5.00%	5.00%	0.00%	0.00%
7	80.00%	10.00%	10.00%	0.00%	0.00%
8	90.00%	5.00%	5.00%	0.00%	0.00%
9	55.00%	20.00%	15.00%	10.00%	0.00%
10	90.00%	5.00%	5.00%	0.00%	0.00%
11	65.00%	10.00%	15.00%	10.00%	0.00%
12	60.00%	15.00%	15.00%	10.00%	0.00%
13	60.00%	15.00%	15.00%	5.00%	5.00%
14	80.00%	5.00%	10.00%	5.00%	0.00%
15	80.00%	15.00%	5.00%	0.00%	0.00%
16	55.00%	35.00%	5.00%	5.00%	0.00%
17	20.00%	40.00%	20.00%	10.00%	10.00%
18	5.00%	30.00%	40.00%	15.00%	10.00%
19	10.00%	20.00%	25.00%	30.00%	15.00%
20	0.00%	0.00%	15.00%	35.00%	50.00%
21	0.00%	0.00%	5.00%	40.00%	55.00%

Table 4.3: Results of Survey for the Control Group for Study 3

Hypothesis	**Question**
Does Metazoa Ludens provide empathy towards the pet?	1) Do you feel increased empathy towards the pets during gameplay? 2) Do you feel increased empathy to the pets after gameplay?
Using Metazoa Ludens on a regular basis would improve empathy to the pets.	3) Would playing Metazoa Ludens on a regular basis promote empathy to the pets than without it?
Users show more empathy through the use of Metazoa Ludens.	4) Overall, do you feel more emotionally connected to the hamster through the use of this system, compare to other forms of remote communication (such as webcam)?
Users prefer Metazoa Ludens to have connection to living pet.	5) Do users prefer to play the game where the virtual hamster is directly connected to the real hamster or where it is purely virtual, controlled by computer.
Effectiveness of Metazoa Ludens as Empathetic Media	6) On a scale of 1 to 5, how effective is Metazoa Ludens as an empathetic media?

Table 4.4: User Evaluation Questions based for Empathetic Media

Qn	Options				
	5:Yes, very	4:Yes	3:Fairly	2:Not really	1:No
1	60.00%	30.00%	10.00%	0.00%	0.00%
2	50.00%	40.00%	10.00%	0.00%	0.00%
3	50.00%	20.00%	30.00%	0.00%	0.00%
4	60.00%	20.00%	20.00%	0.00%	0.00%
5	40.00%	50.00%	10.00%	0.00%	0.00%
6	70.00%	20.00%	10.00%	0.00%	0.00%

Table 4.5: Results of Survey for First Group for Study 4

Qn	Options				
	5:Yes, very	4:Yes	3:Fairly	2:Not really	1:No
1	20.00%	30.00%	30.00%	20.00%	0.00%
2	10.00%	30.00%	40.00%	20.00%	0.00%
3	10.00%	50.00%	40.00%	0.00%	0.00%
4	10.00%	50.00%	20.00%	20.00%	0.00%
5	40.00%	40.00%	20.00%	0.00%	0.00%
6	20.00%	30.00%	40.00%	10.00%	0.00%

Table 4.6: Results of Survey for Control Group for Study 4

Overall comparing the results in Tables 4.5 and 4.6, for the first group for all six questions we do not have any users selecting the options 'Not really' and 'No'. On the other hand for the second group (control group) for all six questions, we do have some users selecting the options 'Not really' but none selecting 'No'. This shows that overall the first group responded more positively to the hypotheses explored in this study relative to the second group. As the only difference between the first group and the second group is the fact that the second group does not know the pet avatar was controlled by a real hamster hence the differing results could only be due to the control group thinking that the questions are based on their interaction with the pet avatar in the game. As one of our main aims in the game was to prove that

our game was a case of Empathetic Media, which effected users on an emotional level, the results of the survey are promising.

Questions 1 and 2, in the first group - those who aware they were playing with a pet - 60% responded positively when asked if they feel increased empathy to the hamster during gameplay (in Question 1). 50% of these users said that they felt more connected with hamsters afer gameplay (in Question 2). In contrast, only 20% of the second group claimed to feel increased empathy for the hamster during gameplay (for Question 1), and only 10% felt increased empathy for the hamster after gameplay (for Question 2). This shows a clear connection: those aware of playing with a pet feel more connected to them afterwards; whereas those not aware of playing with a pet, don't. Through playing the game, users became more connected to their pets - the game helped them to forge emotional relationships with their hamsters.

Questions 3 and 4, in the first group, a huge percentage of the users (50% for Question 3 and 50% for Question 4) selected '5: yes, very' while for the second group a significantly small percentage of the users (10% for both Questions 3 and 4) selected '5: yes, very'. Comparing this result between the first group and the control group, it shows that basically users feel that Metazoa Ludens is able to promote empathy and emotional connection to pet having known that they are actually playing with a live pet.

Question 5, in the first group, there were more users selecting '5: yes, very' and '4: Yes' than the second group. This proves that users prefer to play with Metazoa Ludens that is controlled by a live hamsters rather than one controlled by the computer.

Question 6, whether the users felt Metazoa Ludens is effective as a Empathetic Media. The first group 70% selected '5: yes, very'; whereas the second group answered only 20% selected likewise. Being aware of playing with a real hamster makes users feel that the game is effective as Empathetic Media: even, it may guarantee that users will feel more emotionally involved. Further, more of first-

group users answered '5: yes, very' to this questions, compared to the control. More users in the first group felt very emotionally engaged during gameplay.

Based on the results obtained from the two groups it is shown that Metazoa Ludens does add on more emotional ties from the human users to the interaction game system hence showing that our fourth study is positive, Metazoa Ludens is effective as Empathetic Media.

4.5 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 and Living Media, but also to provide lessons of wide applicability for human-animal interactive media.

A possible framework or set of design guidelines used to describe human-animal interaction system and the interactions involved may be developed from the built 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 the human and the 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 systems to be built. Knowledge learnt 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. This may make way for greater future communication between human and animals as well as better interaction methods using Living Media.

There has already been extensive literature and research on design principles for human-computer interaction systems [74]; 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 human-animal interaction system are presented. These arise from thinking upon 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 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 is instinctive to what the animal normally do; Learnt, where the animal requires 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 chasing after a ball, it would be better if you could throw the ball while your dog runs after it. It thus become a consideration to allow interactivity in the human-animal interactive system. Choices available for this dimension are - None, where there is no interactivity between human and the animal; One-way where interaction is only one-way; Two-way where interaction is two-ways.

- **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 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, on the other hand 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; Non, where animals are not given gratification nor given 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 being 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 listing of all human-animal interaction system, since while having an exhaustive list give completeness it may not be required for the development of a human-animal interaction system framework.

These research systems which are included are the same explained and described in Chapter 3: Rover@Home [43], Cat Toy [59], Poultry.Internet [38], Pet Zoo [58], Infiltrate [49], SNIF [60], Netband [61], Crickets Pacman [50] and Metazoa Ludens.

4.6 Analysis of the Framework

The end for this chapter comprises of a detailed analysis of these different systems, providing both a categorising and scoring system, along with future recommendations for game development.

Figure 4.5 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 human-animal interaction system (after pattern language for architectural studies [75]) are thus obtained. These four archetypes are: **Restricted Interface, Discretionary Contact, Digital Live Display,** and **Interactive Connection**.

Restricted Interface accounts for 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 to the human. Such systems are mostly intended to have a restricted one-way interface focusing on the human's interaction with the animal. As Empathetic Media, though these systems deliver emotional-engagement on the part of the human user, this empathetic dimension is restricted as engagement is one-way. Whilst users can act on their pets; there is no way of properly gauging pets' reactions, or of pets being able to respond in many ways to their users.

This is partly due to the fact that both systems reproduce what can be enacted in "real life" without using the virtual dimension of the technologies to go beyond this in interesting and innovative ways. Both systems act as useful tools for pet-owners who are a busy or geographically distant for their pets - and in that, are primarily aimed at providing ease of mind for users, rather than being aimed at strengthening the bond between both pet and owner in the deeper way we have demonstrated is possible with a system such as Metazoa Ludens.

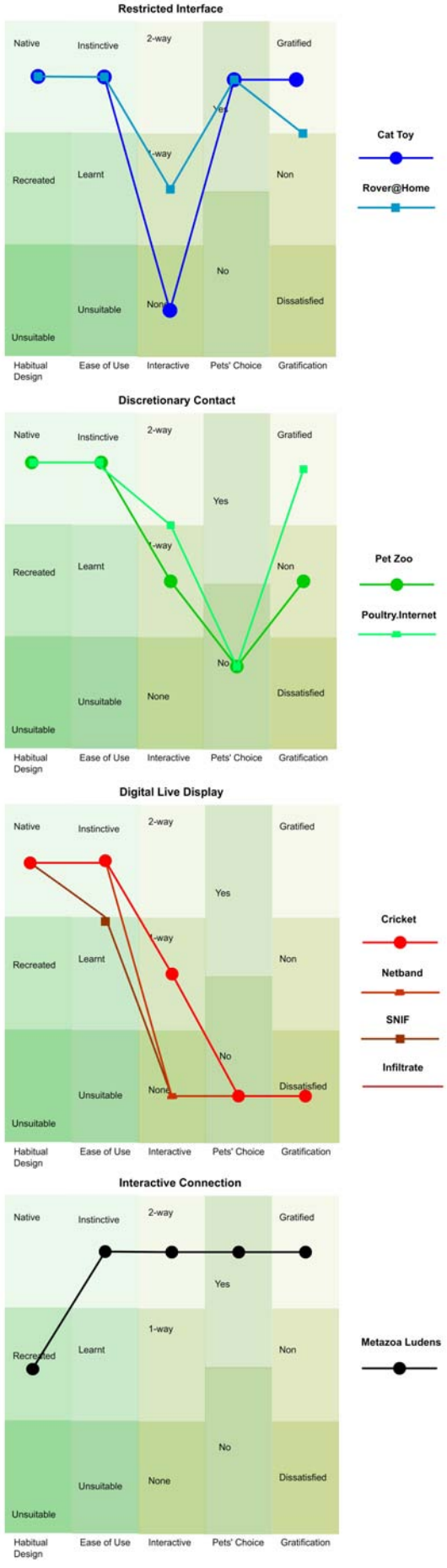

Figure 4.5: Human-animal interaction systems across five design dimensions

Discretionary Contact accounts for Poultry.Internet and Pet Zoo. Such systems score fairly well in four of the dimensions except for Pet's Choice. Despite the animals having little choice in participating in this interaction nevertheless it is noted that gratification or benefits for the animal is high. In the case of Poultry.Internet while the chicken has no choice as to be patted by the human, however 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.

Whilst it could be argued that there is little to the notion of a pet's "choice", it is important to note - as we have done in previous analysis - that pets will respond positively to activities that they enjoy and have a variety of options available within. Again, these systems are primarily aimed at user enjoyment, with technologies used to reproduce standard "real life" contact between pet or animal and human, without striving to go beyond this.

Digital Live Display accounts for 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.

Partly, this seems down to the fact that the pets are not represented as being pets in these systems, or the animals are not represented as being animals. Indeed, Cricket Pacman's digital display is premised on the idea that the user sees Pacman ghosts as being ghosts, and not indeed as crickets. As our testing results from Metazoa Ludens show, emotional engagement, and hence Empathetic Media, is delivered when users have an awareness that they are digitally engaging with animals. This is facilitated by the main focus of the game or system being the actual animal themselves, helped when the animal is represented as such by the digital system.

We have diagnosed both strong and weaker versions of the concept of Empa-

thetic Media throughout our research. Weaker versions of the concept understand empathetic media systems as being those that use technology to aid the relations between pets or animals and their owners. On this reading, something as basic as a dog lead or a hamster wheel could be seen as empathetic media, as both aid pet-human relations in emotionally-satisfying ways. However, stronger versions of the concept will involve the idea of digital technologies being key, and those that go beyond reproducing or augmenting "real world" scenarios for the user. As such, the digital display is an important component of empathetic media systems, as it allows the user to see their pet and respond to it accordingly.

Interactive Connection accounts for 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.

As we have outlined throughout this chapter, in order to deliver a stronger concept of Empathetic Media, it is the interaction between animal or pet and owner that is most important. This means developing a system that allows for two-way interaction between pets and their owners. Pets actions and movements are not too confined by the system, so that pets can act in potentially erratic and surprising ways - thus challenging their owners and forcing them to think on their feet and respond in kind.

Our analysis has shown that there is some vagueness surrounding the notion of Empathetic Media, and we would argue that - of the criteria we have outlined - it is interactivity that is key if the concept is to be further delimited in order to make it more meaningful as a category of analysis.

While the four presented system designs can help designers in future design as model for development of new human-animal interaction systems, it does not

represent the only possibilities for building such systems. More importantly will be the use of the five dimensions in consideration of the new design. In an ideal situation any such systems 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 well being has always been considered. Consideration of their interaction with the system should be intuitive and comes second nature to the animals. As such, studies on animal behavior is of utmost importance in selecting appropriately the way for the animal to interact with the system. Most importantly the animal's choice to use the system and their 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.

With the experimental results and generalised framework thus presented, the next chapter shall move on to describe the second iteration done for the research on Living Media.

Chapter 5

dDNA: Self-sustaining living digital systems

This chapter discusses the second iteration and its working prototype named dDNA, from the background to the prototype details and finally the user experience.

5.1 The Second Iteration

From the first iteration, Metazoa Ludens, a framework for human-animal interaction system has been drawn up while knowledge has been gained from such systems. Moving on to the second iteration let us first re-examine Living Media together with what was done and uncovered in Metazoa Ludens.

In Metazoa Ludens as a Living Media, the interaction between human and animal is explored. While we could dive deeper into human-animal interaction systems, at our current stage of exploration we have chosen to explore another possible channel of Living Media to give a broader general understanding of this research area. As we have discussed Living Media is a media comprising of living beings as part of the System: this includes not just animals but also plants . Our second iteration will thus move onto an exploration of plants and nature.

While it is easy to incorporate individual plants into a system's component, to do the same for nature more broadly is more subjective: there are many ways of conceiving of, and relating to, natural systems - meaning that in order to develop successful Empathetic Media, we must choose a dominant interpretation to ensure empathetic responses on the part of users. One way of looking at nature is as an environment created by non-artificial components, something capable of providing an ambient setting and effecting feelings of calm. In a more pragmatic approach to our first attempt at incorporating nature into a working prototype, instead of creating a whole environment of non artificial components, we would try to create a media using plants which is itself capable of giving an ambient calm feeling to the audience/users.

Also for the second iteration we would like to move on to uncover more than just the use of Living Media as Empathetic Media. The first iteration shows that Living Media is capable of evoking more emotions with the human users/audience: our human users were invigorated, excited and enjoyed their experiences, as well as learning to conceive of - and relate to - their pets in new and novel ways. Without these emotional responses built out of a pre-existing relationship of owners with their pets, there would have been little enjoyment of Metoza Ludens as a game - indeed, the principle of the chase game is to effect certain feelings on the part of users. In the second iteration we would like to build on the previous knowledge gained and uncover a more meaningful reason for using Living Media as a means to Empathetic Media. The use of Living Media should represent more than a need to evoke emotions in the human users/audience, since there could be many other ways to evoke emotions in the human users. It should be used to begin to evoke emotions for a purpose unique to the type of emotions such software is capable of evoking .

Living Media is capable of being used as Empathetic Media due to the empathy humans feel for other living and growing things. One feature of Living Media is that parts of it thrive whilst others decay - it is a dynamic system. It is common for human beings to respond positively to natural growth and negatively to its demise. For example, a gardener watching her rose grow will feel gratified and proud

- whereas watching it wilt will be saddened, perhaps even attempt to save it from dying. Over time, however, the gardener will learn that it is a fact that roses die, and she will stop trying to achieve what she thinks is impossible - namely, saving the rose. The living and dying of the rose becomes a 'natural process', and the gardener forgets that it is her action that has planted the rose, her intervention that has helped to keep it alive, other people who have developed its certain colour and shape through cross-fertilisation over decades - and, perhaps, her who can develop new and novel ways to create longer-living roses in the future. Thus, we hypothesized that as the Living Media conveys its state of well being through its displayed condition, the emotions it evoked would differ accordingly to its physical state. Further, such emotions evoked may sometimes lead to actions on the part of the human audience/users. Hence the different physical states - thriving and decay - of the Living Media may be used to communicate with the human audience/users in order to protract specific responses

One possible candidate for delivering such humanistic information relating to something that thrives and decays according to one's actions and interventions is the relationship between loved ones (given by parameters such as the communication level between them) or one's health status (given by parameters like blood pressure or cholesterol level). For example, good communication means that a relationship thrives; whereas high blood pressure means that health deteriorates. Furthermore, the use of Living Media to represent and communicate humanistic information is most appropriate since the empathy one would feel for say a the conditions of relationships with loved ones or one's health condition can be reproduced by the empathy one can feel for the thriving and decay of nature itself.

In addition we would like to take on a stricter definition of Living Media. Rather than a straight forward case of having the living being interacting with humans through the system (as in the case of Metazoa Ludens,) we would like to have a media with parts of it made up of living beings/organisms.

This thus forms the basis for the working prototype for the second iteration where bacteria (E. coli) will be used as the living component of the Living Media

and will be used to give an ambient calm feeling to the human audience to emulate the ambient calmness which nature can often give. The living being in this case will be used to communicate humanistic information to the human audience as it thrives and decays. Also, rather than having a prototype which allows the human to interact with the living being (E.coli in this case), the living being will form parts of the prototype itself to adhere to a stricter definition of Living Media.

We next go on to exploring related literature from which an overview design concept and objectives for the second working prototype is derived.

5.1.1 Literature review of related works

There are several key areas of research related to our Empathetic/Living Media and these provide the background research for this iteration.

The first area of research pertains to user-interaction issues. We present examples of related works that engage the user in a manner similar to our studies. Another key area that supports the research pertains to living organisms. We will present related examples of living organisms which are a kind of media/system, that is Living Media [76]. With respect to this area, we are also concerned with the issues surrounding genetic manipulation and its recent developments.

Communicative Ambient Media

The dominant interpretation of today's Western culture is one of an 'information age'. Following in particular the publication of Nicholas Negroponte's pioneering work, Digital Age [77], sociologists, cultural critics and commentators alike generally agree that today, people are busier than ever, often distracted and overloaded with more information than they can process.

Researchers from different areas are therefore developing different methods to provide information in more effective ways by appealing to various sensory channels, through finding ways to subtly and less obtrusively dispense information. In particular, calm technology and ambient media make information available to users in new and novel ways.

Calm Technology [78], a concept developed in particular by Mark Weiser and John Seely Brown in the mid-nineties, urges peripheral awareness of activity in the virtual world or mediated through the virtual world. Usually using colours and sometimes movement to represent different data-types and their inter-relationships, the principle behind such technology is that it can ultimately broaden and enrich human experiences - further, that more information can be calming in and of itself when represented in the right ways [79]. Ambient media [80], developed mostly by advertisers aiming to better reach their target audiences, works on a similar sort of principle, in that it establishes a connection with people through altering some aspect of their surroundings. The idea here is to try to somehow tie the mode of communication of the information with what the information is about, or at least to present information (usually branding) in unexpected places, so for instance, on the side of hot air balloons.

Example of recent works in ambient and calm media include "ambientROOM" [81] is a room that has a range of information displays integrated into its architectural structure. LumiTouch [82] is an augmented photo-frame artifact which allows a remote couple to feel each other's presence and abstract feelings for each other. And Pocomz [83], is a communicative ambient display, where the online status of selected chat pals are displayed in a non-intrusive manner through ambient lighting.

The above systems however, are based on non-living objects. They are technologies built entirely from digital systems, usually representing fairly standard information on a 2D screen. The effectiveness of such media in being able to adequately communicate to users is therefore most probably constrained - in these instances - by the users' pre-existing relationship with such digital technologies. It is suggested

that a person who is more used to the idea of using display screens to represent abstract emotional information, for example, will be more open to the possibilities and opportunities offered by ambient and calm technologies, then somebody who is not accustomed to dealing with abstract data represented in new and often digital ways.

We will therefore explore the literature surrounding living media - that which plays a similar role to calm and ambient technologies - but employs living organisms as its mode of communication as opposed to digital screens.

Empathetic Living Media

People have often partnered themselves with living organisms to assist them in many aspects of life. In many cases throughout history, man has used living organisms - animals and their behaviours - to inform them about, for instance, environmental threats - such as water and air pollution. Living organisms have been used to communicate information to people, to represent certain states of affairs to them.

For instance, early coal miners unlike miners today did not have the special equipment to detect dangerous methane gas in the air, so they went together with canaries to indicate air quality issues in the mines. Having learned that canaries were more sensitive to methane gas than human beings, miners used this knowledge to their better advantage. Even today, fish are assisting people in the detection of chemical contaminants in public water supplies. For instance, a water security system [84] analyzes the behavior of eight to twelve bluegill fish in a tank at the San Francisco Public Utilities Commission's water-treatment plant in Millbrae. Inside the tank, there are instruments that watch the behavior of the fish and can detect the coughing activity of each one. The instruments transmit their findings to nearby computers, which compare the fish cough rates and other behaviors to their normal behaviors. If the computers detect that the fish are upset by something in the water, the system immediately triggers water samples to be taken for further investigation.

I/O Plant [85] is a system that takes this principle yet futher in utilising plants as an input/output interface. Information about the plants is translated by a computer and represented to users - who can in turn interact with the plant through the system. Thisis a good example of how interaction between nature, humans, and computers is possible, straightforward, and beneficial.

On top of using plants as part of a Living Media system, various glowing living organisms have also been developed previously. For example, Glowing Green Pigs [86], rabbits ("GFP Bunny") [87], and Zebra Fish [88] have been made to glow under blue and ultraviolet lighting.

Nonetheless, in those cases, the genetically-engineered organisms are created with the glowing ability, and the glow cannot be switched off or controlled. Therefore, they do not represent an interactive media with communication abilities, but constitute an important step in the development of a fully interactive living media.

Building on this research and aiming to develop on previous examples, the second prototype could use a non-intrusive biologically-generated glowing light - which has an ethereal quality most suitable to represent abstract social/emotional qualities such as those involved in relationships and ecology. As the theoretic work behind the development of Calming Media has shown, complex information can be best represented through unobtrusive displays of colour and sometimes movement. The emotions protracted by an ethereal light can both communicate and calm. This can also be used as a means for dispensing information subtly.

Adding on to this is the use of living organisms which can also thrive or decay, hence enriching the semantics behind the fragility of the emotional/social aspects (such as relationships) within the human community that is communicated by the second Empathetic/Living media.

As such for our second prototype, there should be a glow level that could be computer-controlled and hence used to communicate certain information through a digital system. This actually builds on the initial goal of the creator of the glowing

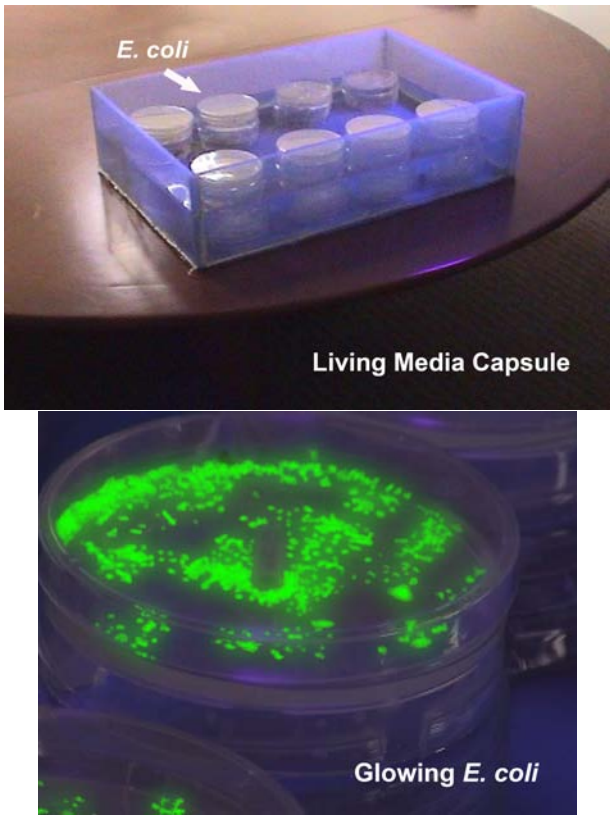

Figure 5.1: Empathetic living media capsule and close up of glowing *E. coli*

rabbit [87], which is to integrate genetics with communication and interaction, such that the glow displays more than an unconventional phenotype of the organisms, but is used in certain ways which information and data may be passed.

5.2 Overall design concept of dDNA and its objectives

Based on literature reviewed a non-intrusive biological generated glowing light would be used to form part of the component of the second prototype. A possible way to do so is to use DNA of both glowing jellyfish and sea pansy to create a green glow like that used in the glowing organisms previously mentioned. Since this living organism will be used to form part of the prototype *E. coli* which is a primitive living organism (plant) that has a high multiplying rate as well as ability to survive

in harsh environment, is chosen as the living organism to form the living component of the second iteration.

Since this second prototype should be able to thrive and decay accordingly to humanistic information through the use of a closed-loop control capsule, the second prototype should be able to control the organism's thrive and decay and hence its glow. The second prototype is thus named dDNA which translates to mean digital DNA since DNA has been changed and control of the organism's glow given to digital means. Shown in Figure 5.1, dDNA will be a system that uses living organisms as part of a novel digital ambient media. Social, human, and ecological variables such as interactions amongst loved ones, health, and ecology of ecosystems are translated with meaningful semantics of human users' empathy for living creatures through the control system capsule to the organism's glow.

There are two main sources of motivation behind this research. Firstly, to inform through ambient empathetic living media that promotes human empathy the social and organic happenings around a person's life As the gardener would prefer to intervene and stop her rose from dying due to her empathetic connection with her plants, but can't, so we afford all human users the ability of controling wholescale the level of thriving and decay of the Living Media based on the same intuitive empathetic responses to thriving and decay. Living things evoke feelings due to empathy that are different than what can be evoked by artificial or digital imitations. This is based on the fact that humans have true empathy only for creatures they consider to be alive [89]. Secondly, the use of living organisms to represent the significant portions of one's life adds semantics to the manifestation - since social aspects such as relationships and addictions thrive and decay, so would the living microorganism. Thus, by tying together digital media with the living world we can develop media that especially promotes empathy about social and ecological information.

By taking chosen inputs from social or ecological life, the control system adjusts the fluid flow rate, adjusting the glow of the empathetic living media in real time.

For example, our empathetic living media literally grows brighter or dimmer as monitored by the control system capsule according to human social information such as communication time spent with family. By seeing a living ambient representation of family communication time, a person can be encouraged to make more effort to spend time with his children, or her grandmother. On the other hand, a person who has addictions such as smoking cigarettes can be encouraged to make an extra effort to cut back when she sees the microorganisms representing his addiction to tobacco dim in their glow and decay - a very semantically meaningful and living representation of what is happening inside her body. Visualizing this human and social information in the form of fragile empathetic living media places a much greater semantic meaning and coupling to the data than non-living displays.

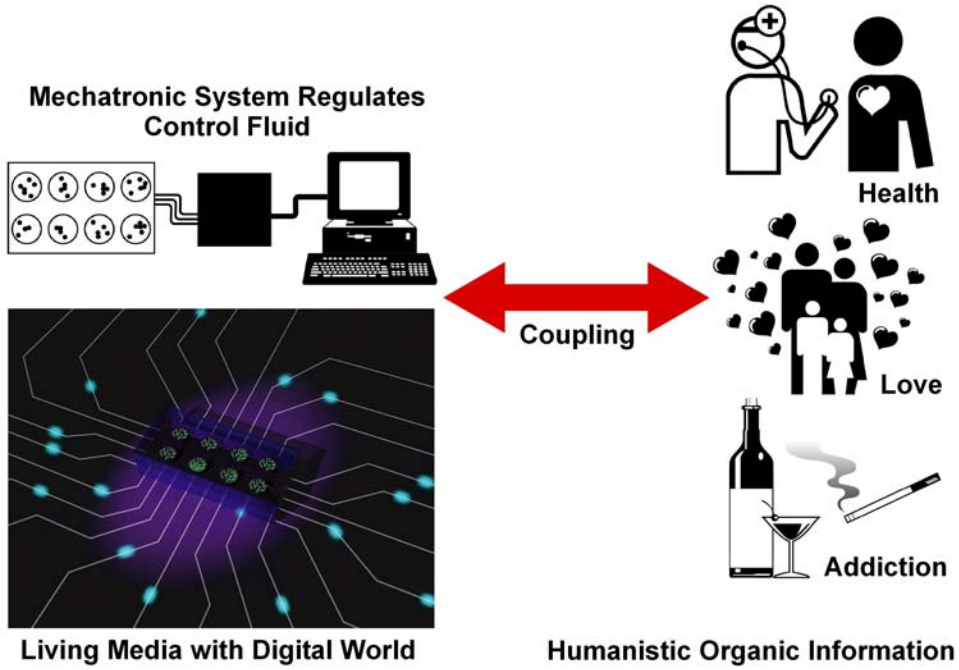

Figure 5.2: Impedance matching of empathetic living media with humanistic organic information

We hope that by radically exploring the realms of empathetic living media the boundaries of technology may be challenged, and new waves of innovation may be brought forth through the use of other living organisms to create novel forms of interactive empathetic living media. It is most important to have an impedance match between the coupling of the input and output of the media. In this case the

media is living, and can grow, reproduce, feed, and decay. Therefore we propose it be tightly coupled with digitally measured information which represents social, human or ecological information such as families, health, emotions, ecosystems etc. This is outlined in Figure 5.2.

With the design and the objective of dDNA described we next move on to describe dDNA as a system.

5.3 The System

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

5.3.1 Control System Capsule

We have developed a novel control system capsule (see Figure 5.3) that can automatically control the glow of the bacteria (both for biofluorescence and bioluminescence which will be addressed later). The system operates by carefully adjusting flow of control fluid (Luria Broth, LB, for biofluorescence and luciferin for bioluminescence) in the agar plates containing the bacteria.

As mentioned previously in related work done, the use of GFP to create glowing organisms has been done before with rabbits and pigs. Nevertheless the core technical innovation in this project is creating a real time closed loop control system to control the LB or luciferin control fluid available to the glowing *E. coli*, and

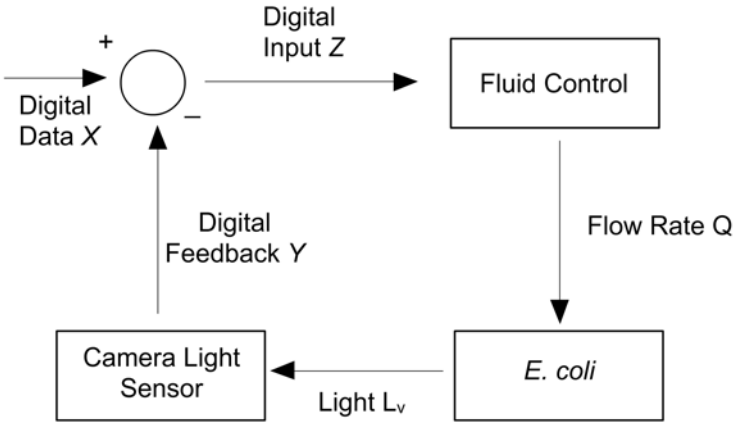

Figure 5.3: System Architecture

thus controlling the amount of glow. Thus the glow of the living microorganism is computer controlled by digital data. The closed loop control system must operate under high non-linearity as there is non linear relation between the flow rate of LB or luciferin and the resultant output glow. This system is unlike the other glowing living organisms previously created, whereby once born the glowing ability is permanent and cannot be changed. Harnessing this ability to control the glow, a communication system is created in the form of ambient media and information is dispensed to users using the glow of living organisms, thus creating an interactive empathetic living media.

The main concept of the control system capsule fashions itself after the biological homeostasis process whereby based on feedback the system is capable of regulating itself. Like any homeostasis process the control system capsule contains firstly a source of input to trigger the process, a source of output for reaction to the input, and a feedback loop to regulate the output source. Based on the requirements of the users, various types of information may be mapped to the empathetic living media through the control system capsule. This information is taken in as a digital input to the control system capsule. Considering the case of communication between loved ones, input data may come in the form of amount of phone calls, emails and

internet messaging between the users. This information is then given to a control system capsule through a simple external workstation. The way of obtaining such information may be through the use of simple protocols much explored in other research [85].

The core of the control system capsule consists of an output module (for activating the glow) and a feedback module (for controlling the glow) both running within the control system capsule. Upon receiving digital input from the external workstation, the output module senses the current control fluid concentration with a sensor. With this information, it next calculates the amount and concentration of the fluid needed in order to attain the desire glow level and releases the amount of control fluid to the plates of empathetic living media. This is done by control of valves connected to supply of the control fluid. A relatively reduced amount of this control fluid will also flow into a relative reduced size dish of *E. coli*, called the control dish and hence activating the feedback module.

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

The control system must deal with high non-linearities, as the relations between the input digital data and output light are related through the non linear function of LB or luciferin to glow of the bacteria. Furthermore the time constants of the various components of the control system (valve, fluid flow rate, bacteria glow change rate) are highly different. To control the system we used gain scheduling control method which use a series of simplified linear controllers [90].

The system was tested and ran robustly in multiple environments (office desk, living room, student dormitory etc.). The time constant for the change of glowing (as

is explained below) ranged from almost instantaneous to approximately 20 minutes, depending on the method of glow that is used.

The next section describes the use of biofluoroscence and bioluminescence with further discussion on the control fluid's control on the glow of the empathetic living media.

5.3.2 DNA Altered Bacteria

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

Biofluorescence

The first type of E. coli that we used was the bio-fluorescent Green Fluorescent Protein (GFP) strain which under the presence of a UV light source, fluoresces in a visible green color. To be used as a controllable unit of light, the growth of the bacteria is manipulated by altering the nutrient level. The growth and glow of the bacteria is dependent on the LB (Luria Broth) nutrient/sugar concentration, surrounding temperature, and the presence of ampicillin in the agar plates. The nutrients are food source for bacteria; growth is optimal for *E. coli* at 37 degrees Celsius [91]; ampicillin will generate selective growth (i.e. only bacteria with the ampicillin-resistant gene will grow).

For the use of GFP *E. coli*, the time of change taken for the GFP *E. coli* to regenerate and hence adjust its glow level is about 20 minutes. The control of the glow is a multifaceted process as there are many ways to achieve that depending

on the requirements. Generally the glow of the GFP *E. coli* is determined by the amount of LB given. Variations to this may include adjusting the concentration of LB given and volume given. For example, if given LB with high concentration but low volume this may help achieve high glow intensity but the duration of the glow may not be long since the amount of LB is limited by its low volume.

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

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

Bioluminescence

Bioluminescence is the result of chemical reactions that produce light in a living organism such as in the insect firefly. One of the possible bioluminescence systems that could be use as empathetic living media is the luciferin-luciferase system which is already well studied and researched [92]. In this system, an enzyme (generally termed as luciferase) breaks down a substrate (generally termed luciferin) with oxygen and energy (adenosine triphosphate, ATP) to produce light.

For expansion on empathetic living media on dDNA with bioluminescence, renilla luciferase, a kind of luciferase, is extracted from sea pansy and inserted into the DNA of *E. coli* such that when the complement luciferin (which is ViviRen in

this case) is added to the DNA transformed *E. coli* it will produce light. The reason for choosing ViviRen and renilla luciferase is the availability of modified renilla luciferase which has the ability to react with ViviRen and yet produce light without the need for ATP, thereby reduce the complexity of handling the process.

As this is an enzyme-substrate reaction, it takes place almost instantaneously (less than one second) producing light (seen as white light by the human eye). Control of this reaction is straight forward, by just varying the amount of luciferin given the amount of light energy released may be controlled. Unlike GFP, the effect of varying volume of luciferin has little impact on the glow level as the change (due to the enzyme reaction) is too fast. For example giving a low volume and a given concentration of luciferin versus giving a high volume and same concentration of luciferin will cause the low volume to light up just as brightly as the high volume in just a matter of few minutes difference. The glow of the high volume may last longer but again the difference is but few minutes unless the volume gap is really large.

Thus as seen, control of bioluminescence is fast and straight forward, making it ideal for applications which requires fast reaction time. Further the use of white light (with no UV light required) may make it appealing to a separate group of audience.

Biofluorescence vs Bioluminescence for Empathetic Living Media

As discussed, both types of DNA altered *E. coli* have their own distinctive glow and glow control. In addition, the Biofluorescence *E. coli* costs about 2/3 of the cost of Bioluminescence. The differences are summarized in Table 5.1.

Comparing the two it would seem like bioluminescence is an easier and more straight forward empathetic living media to implement while giving a faster reaction time, nonetheless it would be noted that for certain audiences the multiple colors

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

Table 5.1: Biofluorescence and Bioluminescence

available with the biofluorescence may be a desirable trait while the ability to have a fast response to digital data may suggest using bioluminescence instead.

5.4 Design Approach

In this section we will detail the approach to designing the living media system by describing a user experience of this ambient interface.

5.4.1 Scenario of User Experience

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

Such soft glow is capable of staying in the background of the home or office in an ambient manner, merging seamlessly with the background (this thus also satisfy our initial objective of recreating 'nature' which gives a ambient calm feeling that the human audience may feel a connection to). Such information thus does not demand

attention while settling into the environment. Besides being an ambient media, the watch of soft glow that is living gives a calming effect to the user; the feel of a media which is alive yet controllable by the user herself presents a fragility in the life of the *E. coli*. This may not just calm the user but make the overall experience more enriching.

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

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

Figure 5.4: Empathetic living media information coding

The coding of the empathetic living media in this case would clearly show the communication (measured by number of calls, messenger chats, emails, etc.) one has

with the family from the mapping: the higher the glow, the greater the communication. In another application the glow may be used for personal use like measuring one's health in terms of the cholesterol level: the higher the glow, the lower the cholesterol level is. These applications are outlined in Figure 5.4.

With the dDNA system as described and explained we will next move on to discuss the user studies done on dDNA and the generalised framework thus derived.

Chapter 6

dDNA: Experimental Results

This chapter provides the details of user studies done on the dDNA, the questions used and user studies results. A generalised framework for Living Media system is given based on the literature surveyed previously and knowledge gained from creating dDNA.

6.1 User Studies

In this second iteration we are designing for a general form of empathetic living media ambient interface. Thus, a careful analysis of the user and the context of use helps to answer questions about features and functions of dDNA, the working prototype thus derived, and an understanding of users' needs or desires. The examples of earlier ambient systems help to build a case for general interactions using empathetic living media. Additional information such as color preference and emotional attachment to living displays is tested as well.

In previous projects which involved electro-mechanical systems, the user is fully aware that electronics and logic are responsible for the display of information. As in the Ambient Orb, electric lights provide the glow and although the transitions of

colors and intensity are gentle, the user is aware of the cold, digital nature of the device. We hypothesized that the users map information differently for empathetic living media. To understand some general aspects of the user opinions, we developed a user study made up of a mix of closed and open ended questions. This study helps to focus efforts in the design and use of the prototype and helps isolate issues that may require more in depth study to understand the user. The questionnaire was focused at answering the five design questions of our current system. The questions are presented below with our hypotheses as well.

In this study, users experienced the empathetic living media system by observing two forms of dDNA capsule (Figure 5.1) for one working day in an office setting. One of the capsules used biofluorescence and the other used bioluminescence *E. coli*. In order to conduct similar tests for each user, the data that was input to the display was identical pre-captured data for each test run (however, apart from this, the system was running live and in real time). One set of data corresponded to the number of chat messages per hour between two friends to provide an example of social communication. The other set corresponded to the pollution index of Singapore air to provide an example of environmental data (the data was compressed to represent a 1 month period to be shown to the user in one day). The biofluorescence display was used to indicate the pollution index, as the time constant of the display is approximately 20 minutes, which is suitable for slow changing media. The bioluminsence display has almost instantaneous change, and is therefore suitable for displays of real time social communication, such as our chat message data.

An example of one of the experiments with participants using the ambient living display on their office desk is shown in Figure 6.1. One part of the user feedback is to compare exactly the same visual display in both living and non living form, to determine if there is any difference in the empathetic feeling for the data by the user. In order to do this, the user was presented with an application which would run on their computer. The application contained a 3D virtual reality version of the empathetic living media capsule display which was fed by the same data. To a good approximation (although not exact, as it is almost impossible to exactly model the

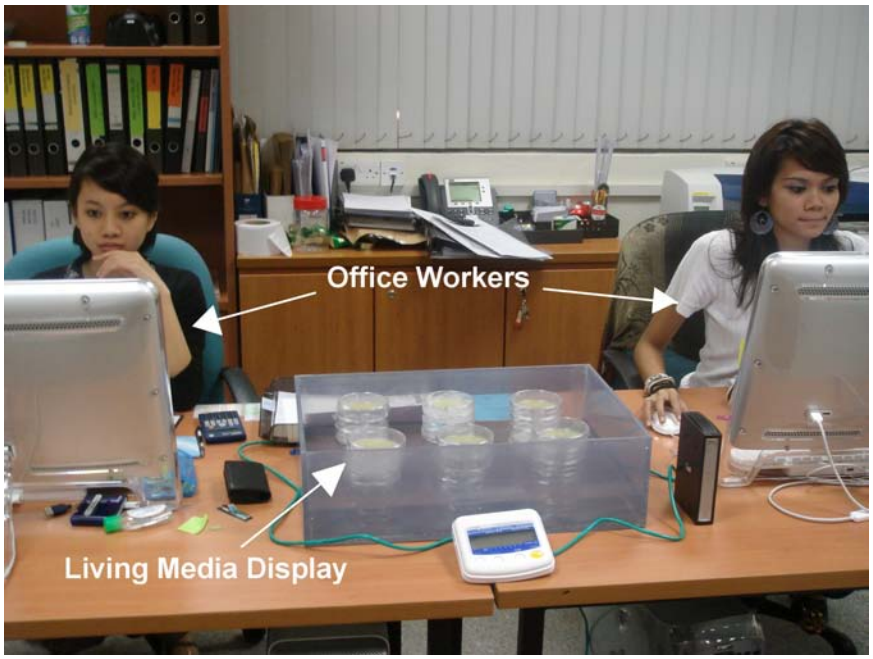

Figure 6.1: Office workers with empathetic living media ambient display on desktop

real time glow of the living bacteria), the virtual reality version presented the same visual display to the user, except it is in purely digital form. An example of the user running the virtual desktop version can be seen in Figure 6.2.

The user was instructed as to the nature of the data in each display, as well as the time constants involved. The user was informed to observe the display in their office, but to carry on the normal day to day office activities, since the display is meant to be ambient and used in the background. After the one day experiment, the users were asked multiple questions.

As part of the administration of the study, the respondents also watched a video with explanation of the dDNA project. Additional verbal explanations were given to explain the concepts of Ambient media, Calm Media, and Empathetic Living Media. As part of the explanations, the respondents were given the paper about Pocomz [83] and were asked to consider this type of media as an example of Calm, Ambient Media. This served to help the respondents develop opinions about the genre and to provide more meaningful input regarding their acceptance of the technology.

Figure 6.2: User seeing pure digital version of living media on computer desktop

6.1.1 User Study Questions

The user study questions and hypotheses pairs are as follows:

1. **User Acceptance of Ambient Media**:

   Question: How do users feel about Ambient Media?

   Hypothesis: Users will generally enjoy the idea of Ambient Media and express desire to have interaction with Ambient Media in their everyday lives

   Example Question: "Do you think Ambient Systems would be useful for you?"

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

   Acceptance of System

   Question: How do users feel about Empathetic media and what emotions are associated with the system?

   Hypothesis: Users will generally enjoy the idea of Empathetic Media and

express desire to have interaction with Calm Media in their everyday lives.
Example Question: "Considering the test do you think Living Media provides more empathy for the representative data?"

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

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

4. **Empathetic Living Media Information Mapping**:
   Question: What issues can be represented with empathetic living media specifically?
   Hypothesis: Users will show preference to displaying emotionally engaging issues through empathetic living media and will provide more examples of using empathetic living media as Ambient Information systems versus non-living

media.

Example Question: "What social or ecological issues would you like to see used in the project?"

5. **Prototype Acceptance**:

   Question: How do the users experience the prototype and the idea behind the empathetic living media?

   Hypothesis: Users will show positive response to the aesthetics and semantics involved in the prototype, and will show a higher positive response for the empathetic living media presented to the Experimental group

   Example Question: "Knowing that the media is a living organism, how strong is the emotional connection when compared to normal electronic lights? Please circle the answer representing your opinion."

6. **Other Applications**:

   Question: How do users feel about other empathetic living media?

   Hypothesis: Users will be delighted in knowing other novel ways to display information and will show a preference for the empathetic living media.

   Example Question: "There is a type of fish that can be used as a empathetic living media. It changes color very quickly and using control systems, we can provide an interactive display. How do you feel about fish as a empathetic living media?"

6.1.2 User Study Results

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

User Acceptance of Empathetic Living Media

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

User Acceptance of Empathetic Media

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

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

Ambient Information Mapping to Humanistic and Organic Information

As mentioned in the first hypothesis, the users showed a strong acceptance (83.8%) to having the information mapped to human issues and ecological information related to the environment. Similarly, a majority (85.6%) users chose to have the personal information displayed in symbolic representation and also a strong desire (81.1%) for information to be displayed in pixel form. The combination of these two also showed high user acceptance (83.8%). For future studies, we will be creating prototypes which are mapped in the various shapes and asking the user to evaluate the actual physical representation. It may be that for continued use of the system, the user may prefer the display to be reconfigurable and simultaneously mapped to various sources of data. For example, the users may want to cycle through screens of information. Colors seemed to be a recurring theme for most users and surprisingly, the range of

colors associated with emotions varies considerably. While we can presume that the users can learn a color to a meaningful relationship, the personalization of the system may be an added feature to consider (such as mapping red to a loving relationship).

Living Media Information Mapping

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

Prototype Acceptance

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

Other Applications

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

6.2 Empathetic Living Media System Design Patterns

Just like the first iteration, research work done in the second iteration was not aimed at only producing a working prototype, that can be used in home and office

environments, but also through the design and experimentation to construct wide issues of design patterns and frameworks for new types of empathetic living media that can be used by the media interface designer. Besides obtaining user feedback and experience as an input in the design process, formal qualities of existing empathetic living media systems can be analyzed as well. A taxonomy emerges of design archetypes of living media. This benefits future designers of empathetic living media going forward, by helping to locate the proposed system in the existing landscape and quickly identifying varying aspects. This also helps designers to see which design patterns are mainstream or under-represented. The empathetic living media systems available and included for this study are: I/O Plant, Transgenic Zebrafish, GFP Bunny, Glowing Green Pig, Blue Gill Fish and dDNA. Six design dimensions based on observations of these mentioned living media systems are presented:

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

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

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

- **Time Constant**: As a media system would the system be able to react in real time or over a period of time accordingly to users' input. Such time constants

could be - Short, Mid, Long and None (to indicate that the system do not respond and is not controllable at all).

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

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

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

Figure 6.3 shows the six dimensions for the analysis. Colored lines trace the positions of systems on each axis while each axis is categorized into its different categories. Based on the clustering of systems, four design patterns for empathetic living media system (after pattern language for architectural studies [75]) are thus obtained. These four archetypes are: **Inherent Phenomenon, Semantic Interaction, Functional Transformation** and **Transgenic Display**.

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

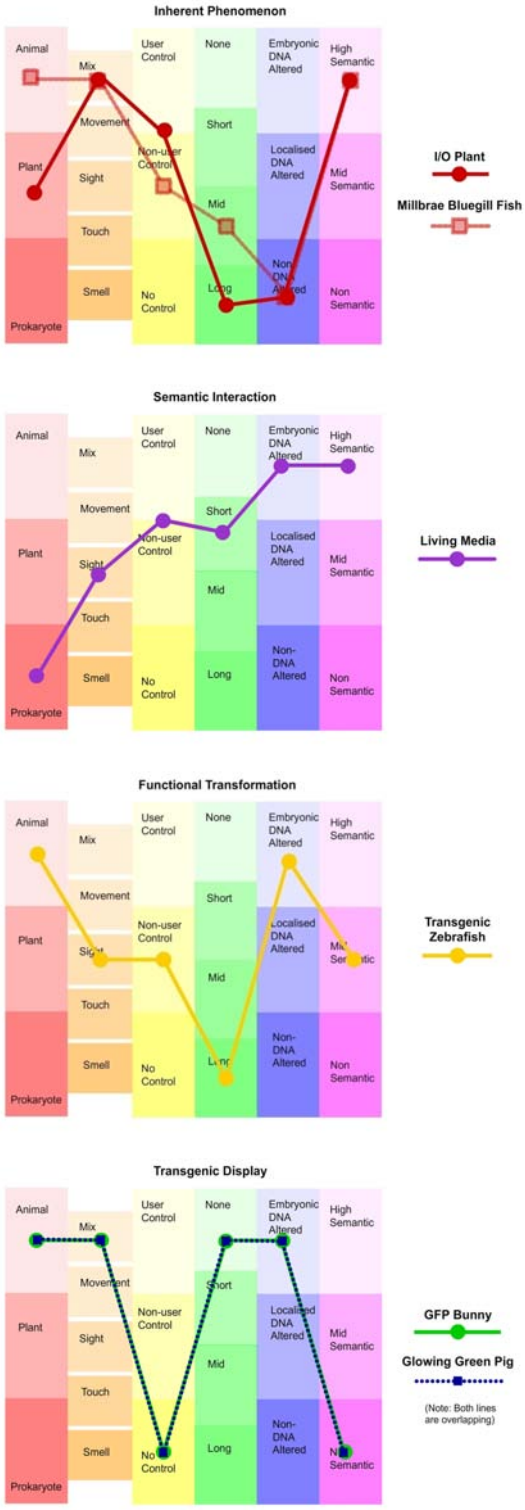

Figure 6.3: Design Patterns for Living Media

Semantic Interaction accounts for our "Living Media" system. The prominent feature of this archetype is the interactivity available that is mapped to certain semantic values. The organisms feature (which is DNA altered) may be changed over time as controlled, and this change is a semantically representation of a certain value of interest to the user. Such systems revolve in creating meaningful interactive media through semantic mapping to various possibilities.

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

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

While the four presented archetypes can help designers in future design, it does not represent the only possibilities for building such systems. More importantly will be the use of the six dimensions in consideration of a new design. There could be various possibilities through different mixes of the categories within each of the six presented dimensions. For example it may be interesting to create a plant which interacts by emitting various smells according to the mood of the user to create certain ambiance within the room.

With both the prototypes, Metazoa Ludens and dDNA, or both iteration thus described and studied, the next chapter moves on to discuss on the conclusions and future works of this thesis.

Chapter 7

Conclusions

This chapter consists of three segments: the first segment states the conclusion of this thesis; the second segment lists the contributions of this thesis to extending knowledge and understanding; lastly, recommendations for further work are discussed.

7.1 Conclusions

Knowledge gained and lessons learnt from the two completed iterations are presented in this section. However, while the knowledge gained is a direct result of research work done on the two working prototypes, it is noted that the studies conducted are for a greater purpose of exploring the various dimensions of the design space of Living Media as Empathetic Media. As shown in the framework we thus developed, we believe that the knowledge gained may be used in a wider application for the betterment of communication between human, animals, plants and nature as well as other forms of media to come. The usage of such knowledge is only limited by the imagination of the inventor.

In the first iteration, the Metazoa Ludens prototype presents a mixed reality game which facilitates gameplay 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.

Whilst not trying to replace conventional interaction between humans and small animals, its aim is to offer enhanced interaction for users through the use of pioneering digital technologies. Whilst imaginary forms of play can be conducted through more conventional interaction, the digital system provides a believable visual realisation of altered realities for the user. Like many Living Media spaces, it further creates a situation that would be impossible in 'real life', namely, a completely altered picture where humans are chased by their larger-than-life small pets. Importantly, the 'empathy' of Empathetic Media is present in a very real sense: human users learn to appreciate first-hand what it is like being a tiny creature in a large world, as human-hamster relationships are reversed through the game. Whilst in the 'real world' the relationship runs one way - from human to hamster - in the digital world, hamsters get to take on the role of humans - something the user primarily is able to experience. This principle of relationship reversal - offered only through digital media - we believe to be key in developing such technologies, and fuller relationships between owners and their pets. Furthermore the system is empathetic towards the pets, since through system users are able to interact with the pets in a new digitally enhanced level (as discussed above). This will result in the users showing empathy to the pets as a result of using the system to interact with the pets. Hence not only is the user's experience enhanced but empathy showed to the pets as well, and this is the primary aim of this and similar technologies.

By conducting user studies, we have confirmed that the game is not only fun for the human users it is also beneficial to the hamsters' health and in the method of Duncan for pets' choice the hamsters are willingly playing the game. Whilst users are able to broaden the horizons of their relationships with their pets - through interacting with them in a completely new environment and inventing new forms of play, they will also be able to reflect on their experiences and begin to conceive their pets in new and novel ways. We aim to develop owner-pet relations - and the

technology is a tool for this end, rather than being an end in itself that should be fetishised. The digital system in one way mediates human-hamster relations, but in another, it facilitates a more direct and thrilling, innovative and exciting experience for the user. Interestingly, this reflects a deeper reason for humans buying and caring for pets in the first place: it is as much for the benefit of the pet, as for the emotional benefit it brings to its owner through various processes, interactions and play. Building on this truth, the system thus does not represent a radical breaking point in human-hamster relations, but constitutes a development in emotional fulfilment for the pet owner. It thus confirms also our hypothesis that Living Media using human-animal interaction is able to evoke empathy in the human users hence giving Empathetic Media.

We not only showed detailed experimental verification and positive results, but deeply aimed this work to provide lessons and frameworks as given for future human-animal media designs intended for the greater benefits of animal and human relations.

In our second iteration Living Media is shown in our second working prototype, dDNA, which is the revolutionary system that enables the use of living creatures as a controllable ambient display. Information based on human and natural information is quantified digitally and communicated in the form of ambient display by computer controlling the glow of living *E. coli*, thus creating a novel media that is alive.

This display shows significant organic and human aspects of an individual's life, ecology, or society and enriches the semantics between mapping of the living organisms to such considerations. Going a step further from our first iteration, the display is self-contained, and needs no living hamster equivalent.

By conducting user studies, we have confirmed that users are receptive to ambient and living media and we have gained an understanding of the type of features users find desirable. Users demonstrated a clear preference for empathetic living media over non-living media in representing human issues. The user study has also

shown that flexibility and reconfigurability of the display characteristics is important when designing future empathetic living media systems intended to make deep emotional connections. Users manifested a strong desire to interact with the systems, change and influence them depending on the length of their exposure and mood, and to see how the system would develop in response. This desire to engage shows clearly that users quickly make emotional connections that they want to explore and develop, and see the personal benefit in interacting with such technologies. The benefits of appealing to the emotions of the user help to make an interface that shows promising possibilities as a technological tool for motivation, relationship maintenance, and awareness of how human subjects can interact with and change their environments. It provides in microcosm a world for the user to play with where anything is in principle possible: teaching users a valuable lesson that they can go on to apply in their daily lives. In many ways, this empathetic media provides an opportunity for self-development above all.

This research was not aimed at only producing a working prototype, but also through the design and experimentation results to construct wide issues of design patterns and frameworks for new types of empathetic living media. These can impact in general for the benefit of media interface designers.

7.2 Contributions to Knowledge

In addition to the practical and usable conclusions of this thesis, the contributions to knowledge are as follows:

Advanced Human-Animal Interaction System: With Metazoa Ludens it is shown that human-animal interaction can be greatly expanded and enhanced using advanced technology; it is now proven that it is possible to create electronic interactive system for human to interact with animals/pets remotely or locally. Playing with real-life animals through digital systems has been shown to not just create

more satisfying game-play for users; but also to protract strong emotional responses on the part of users alongside strengthening their emotional relationships with their pets. The future possibilities of such systems are only limited to the creators' imagination - it could be entirely possible to play computer games with huge animals like lions or even polar bears.

Framework for Human-Animal Interaction System: A framework for use in human-animal interaction system design is given. Future designers could make use of the framework as a guide for building any future human-animal interaction system.

Glowing *E. coli* as a Communicative Media: With dDNA it is shown that living *E. coli* could be made to glow and its glow controlled and made to communicate information with the human users. It is now possible that other living organisms with color changing ability be used as a means of communication.

Framework for Living Media System: A framework for use in Living Media system design is given. Future designers could make use of the framework as a guide for building any future Living Media system.

Empathetic Living Media: With both Metazoa Ludens and dDNA not only is Empathetic Media demonstrated with Living Media, it is also shown that one could achieve empathy for a system through the use of Living Media.

7.3 Future Work

For future development of Living Media, one possible direction could be using the knowledge gained so far and devising possible practical use of Living Media; while another direction will be to move onto a third iteration into researching furthermore into the design space of Living Media. The former is discussed first while the latter is discussed after.

7.3.1 Possible practical use of Living Media

Using the knowledge gained and inspecting the current situation presented by society, possible practical devise of the Living Media is given.

Remote Animal Interaction: There are children who are very sick and have to stay in hospital all of the time and cannot play with animals. With Metazoa Ludens it is entirely possible that such children are now able to remotely play computer games with animals giving them a chance which was previously denied due to their health conditions.

Animal Shelter: A lot of the time, people are too busy to keep a pet and there are also lots of abandoned pets in animal shelters. With Metazoa Ludens it is now possible that these people can log onto the Internet and interact with the numerous abandoned pets in the animal shelter, showering the pets with love while giving gratification of interacting with animals for the humans. This may also help increase the chances of these pets being adopted.

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

Social Activist Fish Arts: Based on transgenic zebra fish developed at the National University of Singapore [88], we aim to create beautiful color-changing fish which will be a living form of social activist art. For example, the fish colors could change to correlate with the number of living endangered species, such as panda and tigers, or the number of HIV deaths, birth or death rates of populations. Not only does the organic humanistic information couple with the living fish media, but it will create an ambient message for social activism in an artistic manner. For instance,

"The number of Panda Bears still living in the wild" or "Number of people in the world dying of smallpox" or any other global issues that interest specific individuals.

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

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

7.3.2 Babbage Cabbage

Having completed two iterations into the design space of Living Media a third iteration may be further explored. In our second iteration we uncovered the positivity of mapping humanistic information to the thrive and decay of living media; however, the use of decay may not be appealing to all audience. In addition, users' interests and priorities may change with time: it may be a good idea to give control of the humanistic information represented at any one time to the human users.

Furthermore, comparing the first iteration and the second, the latter used DNA altered *E. coli* as the living component while the former used a live pet hamster. In using DNA altered *E. coli* the complexity of the system is greatly increased, also certain audience may not like the idea of genetic manipulation. In Metazoa Ludens the use of hamster represented something more lively and 'natural'.

Hence in the third iteration, instead of using decay some property, more inherent to the living component may be used. This could also remove the need to genetically alter the DNA of the living component as well as reduce the complexity of the system. A possibility is using the inherent colour changing ability of red cabbage whose colour changes accordingly to the pH value of the plant. Also in using cabbage it being more commonly known to the average human audience as contrast to *E. coli* may offer a more appealing and 'natural' representation of Living Media as in the case of Metazoa Ludens. As mentioned before, more control on the humanistic information represented at any one time may be given to the human audience. A customizable interface to control the humanistic information represented by the cabbages' colour will be built into the system and control of that given to the human audience. With that a possible third working prototype named Babbage Cabbage is given and described below.

Red cabbages may be used as living media by inserting electrodes into them to control the level of negative electrons and hence the level of positive hydrogen ions. This may in turn change the color of the red cabbages. As such this method could be implemented in a cabbage patch, where the cabbages may change color according to the weather, and thus inform the farmer about the weather forecast. It could also be used as a beautiful home-living ambient media, with cabbages laid out in rows similar to pixels.

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Appendix A

Paper List

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1. JOURNAL and CONFERENCE PAPERS

Accepted / Published

A.D. Cheok and R.K.C. Tan. 2006. Electronic Privacy in Asia: What is the effect of the Fantabulous Kawaii Gizmos, Wireless Privacy Daemons (Waveband: 2.4-GHz) and Orientalism. SWITCH Journal, Issue 21. January 2006.

R.K.C.Tan, V. Todorovic, A.D. Cheok, G. Andrejin, J.K.S. Teh and S.P. Lee. 2006. Metazoa Ludens: Mixed Reality environment for playing computer games with pets. In Proc. of International Conference on E-Learning and Games (Edutainment) 2006, Journal of Computational Information System, Vol. 2, No. 6, pp. 861-865, 16-19 Apr. 2006, Hangzhou, China.

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R.T.K.C. Tan, A.D. Cheok, R.L. Peiris, I.J.P. Wijesena, D.B.S. Tan, K. Raveendran, D.T.K. Nguyen, Y.P. Sen, and E.Z . Yio. 2007. Computer Game for Small Pets and Humans. Paper accepted for publication by Springer Lecture Notes in Computer Science.

R.K.C. Tan and A.D. Cheok. 2007. Metazoa Ludens: Inter-Species Computer

Interaction and Play. Paper accepted for publication by IEEE Transactions on Systems, Man, and Cybernetics–Part A: Applications and Reviews

A.D. Cheok, R.T.K.C. Tan, T. Merritt, O.N.N. Fernando, Y.P. Sen and D.T.K. Nguyen. 2008. Empathetic Living Media. ACM's Designing Interactive Systems February 2008, Cape Town, South Africa.

R.T.K.C. Tan, A.D. Cheok, R. Peiris, V. Todorovic, H.C. Loi, C.W. Loh, D.T.K. Nguyen, J.Y.P. Sen, E.Z. Yio, D.B.S. Tan. 2008. Metazoa Ludens: Mixed Reality Interactions and Play for Small Pets and Humans. Leonardo, MIT Press Journal, Vol. 41, No. 3, pp. 308309.

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Submitted and Under Review

R.K.C. Tan and A.D. Cheok. 2006. Invading Wireless Privacy: Asia's Perceptive. Paper submitted to Special Issue of Mobile HCI on Interactive Technologies.

R.T.K.C. Tan, A.D. Cheok, H.C. Loi, C.W. Loh, D.T.K. Nguyen, J.Y.P. Sen and E.Z. Yio. 2007. Metazoa Ludens. Project submitted to Ars Electronica.

A.D. Cheok, R.T.K.C. Tan, O.N.N. Fernando, J.Y.P. Sen, D.T.K. Nguyen and E.Z. Yio. 2007. dDNA: Living media. Project submitted to Ars Electronica.

2.INTERNATIONAL DEMOS and EXHIBITIONS

Accepted for International Demos for Transvergence, ISEA 2006, San Jose, USA

Accepted for International Demos for Wired NextFest 2007, LA, USA

3.LOCAL DEMOS and EXHIBITIONS

Solar System, IDN05, 9th Nov 2005

Evolution Table, Singapore Science Centre, 10th Dec 2006

4. OTHERS

Invited to be part of a Panel in the conference ICAT (Hangzhou, China, December 2006) for augmented reality aided virtual assistant.

"Invited Journal Reviewer" for special issue on Computational Art as part of the International Journal of Computational Science.

"Invited Journal Reviewer" for Conference of Human Interaction with Mobile Devices and Services 2007.