國立交通大學建築研究所
碩士論文

智慧居家之直覺性界面探討

A study on intuitive interface in the context of smart living space

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中華民國九十七年七月

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ABSTRACT

With the diversity and complexity of the data received for a space, it would be difficult to easily achieve a common agreement, even for just a building information exchange format. There is a strong need for an intuitive interface to help users to understand and control the intelligence behind the physical skin. The objective of this research was to develop an interactive framework for an intuitive interface within a smart living space context. The design of this intuitive interface for existing smart living space facilities, and the interface itself, focused exclusively on information/control. This research presents a framework for an intuitive interface design for an existing smart living space. Finally, I will show how a system to reify this framework was implemented.

Keyword: Smart living Space, Context-aware, Intuitive interface, Ubiquitous computing, Ambient intelligence.

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摘要

在空間中我們會接收到各式各樣的資訊，但多數的資訊是分散在不同的介面上，使得資訊的取得與使用變的複雜且不方便。所以這裡我們使用一個直覺性的實體操控界面，除了可以整合居家所需要的資訊以外，還可以透過這個介面控制實體的裝置，例如門窗。

本研究的目的是提出一個在智慧空間裡直覺性界面的互動架構，並且根據這樣的架構實作出一個智慧空間。透過這樣的空間，使用者可以很方便的藉由直覺性界面獲取他所想要的資訊，也可以操控實體裝置的開關。

關鍵字: 智慧空間、涵構察覺、直覺介面、遍布運算、環境智能

誌　謝

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謝謝雲科大設計運算所的同學，謝謝你們在雲科照顧我。

謝謝我的家人給我心靈上與金錢上的幫助，讓我能無憂無慮的完成學業。

謝謝天上聖母，在我徬徨時給我力量。

最後，要謝謝的人太多了，我只能謝天了。

2008/7/28

翰宏 于家中

Table of Contents

List of Figures

1
Introduction

With the diversity and complexity of the data received for a space, it would be difficult to easily achieve a common agreement, even for just a building information exchange format. In addition, the numerical data generated by the sensors is far from being sufficiently comprehensive for normal habitation. Therefore, there is a strong need for an intuitive interface to help users to understand and control the intelligence behind the physical skin.

Furthermore, in view of the needed data/information, a total turnkey solution for an intelligent building might not be a feasible option at all. Moreover, even with the current available technology, the behaviors of the occupants, or more specifically the personalization needed, make a more intuitive interface for representing partial or particular information an unavoidable problem. We need a new approach.

1.1 Finding an intuitive interface

In recent approaches, intuitive interface design has involved a window, icon, menu, pointing device (WIMP) style of computing device interface to the environment surrounding us. Ambient intelligence and ubiquitous computing researches from computer science have involved numerous theories and experiments in this direction. In addition, the user-centered approach (Ruyter 2003) has also shown its influence in every aspect of design, as well as pointing toward the method used in this research for the design of an intuitive interface. Each domain will be shown in the following section.

1.1.1 AMBIENT INTELLIGENCE

One of most influential technologies developed in the industry is the Philips Research concept of ambient intelligence. As defined in Philips' book about ambient intelligence in design, ambient intelligence has five key characteristics (Aarts 2003). It is: (a) Embedded: distributed devices are connected with each other and integrated in the environment; (b) Context-aware: these embedded devices can recognize the inhabitants and the context surrounding them (Mark van, et al.2008); (c) Personalized: the design can response and react according to individual needs and personalized situations (Nikolaos, et al. 2004); (d) Adaptive: they can evolve and change based on the activities that occur (Zachary and John 2006); (e) Anticipatory: without conscious mediation, the design should be able to automatically adjust based on the behavioral patterns of the inhabitants.

Along with these five points, an intuitive interface has another dimension in its own way. An interface is not an in-between mediation but a two-way channel for reflecting the activities of the inhabitants and the environment surrounding them. The machine should not just wait for the inhabitants to give commands and activate or react based on these, but should sense the desires and adjust to the needs of the inhabitants—the humans (Aarts 2003, Aarts, et al. 2001, Abowd and Mynatt 2004). This is the basis and the fundamental belief of my research.

1.1.2 UBIQUITOUS COMPUTING

While ambient intelligence is a term that is used in the consumer industry, the computer field has come up with a similar but different approach called ubiquitous computing. Ubiquitous computing treats computers as a set of small, invisible computing units that are integrated in an environment (Mark 1999). Moreover, these computing units have to disappear from the sight of the inhabitants.

Ubiquitous means everywhere. Sometimes, the term computing everywhere is used to make it easier to understand the concept of ubiquitous computing (Genevieve and Paul 2007, Gregory, et al. 2002, Marco and Giuseppe 2007, Stephen, et al. 2005). Following this approach, sensor networks, disappearing computing, and wearable computers have gone as far as they can to make this concept into a real computational solution (Hong 2004, Jason and James 2004). If ambient intelligence is the concept for the next generation of integrated computing, ubiquitous computing will supply the vehicle and energy to drive us there. Numerous studies (Gregory and

Elizabeth2000, Hanna, et al.2004, Kay, et al.2002, Vinny, et al.2006) and ubiquitous computing results have shown the possibilities for sustaining my research. More will be elaborated on in the review section.

1.1.3 CO-EXISTING DESIGN FRAMEWORK

The contextual design for the above problem requires a framework to realize a context for this interface. While the methodology we use is described below, this research still needs a framework to analyze the objects in both virtual and physical spaces. The co-existing framework described in Lu (Lu 2005) shows a control mechanism for physical/virtual objects in physical/virtual spaces based on human activity.

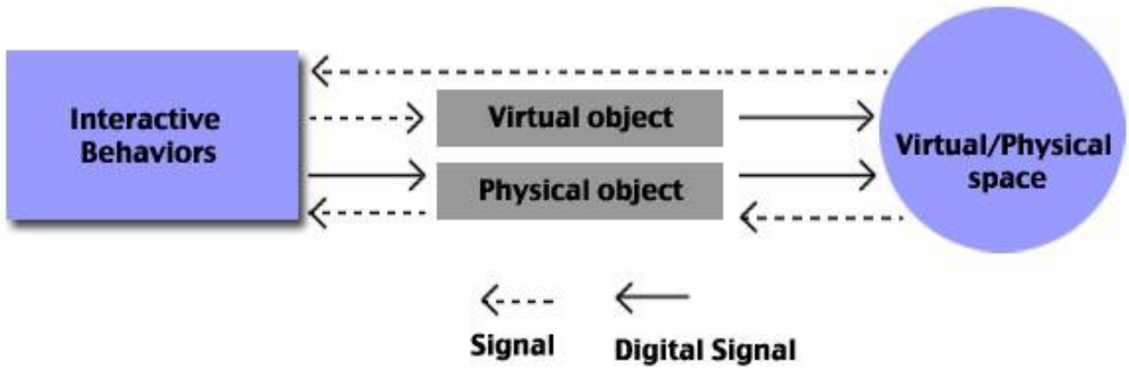

Figure 1-1: Co-existing Framework (Lu 2005)

1.1.4 USER-CENTERED DESIGN PROCESS

Computer design is not just about building a tool to assist users, but is about creating a device that users will depend on and have fun with. This requires a different approach for supporting the concept of computation. From the design aspect, such an approach has a long history, since the functionality and usage of a design depends on its users' feedback and interaction (Norman and Draper1986). The computational engineering fields, such as information technology and electronic engineering, have started to recognize the importance of human activities and the user centered design (UCD) approach (Long and Dowell 1996).

There are four principles to bring the user-centered concept alive (Ruyter 2003): (a) User Involvement: a knowledge of the users' behaviors should be actively involved in driving the system requirements; (b) Empirical measurement: as required by the users, empirical experiments for system measurements should be applied to validate the outcomes and ensure the needs of user activities; (c) Iterative design: with empirical measurement in place, the iterative characteristics of the design process will be applied to system design, to apply an iterative design process to the conceptualization and implementation stages of the digital design; (d) Multi-disciplinary terms: as planned, a focus on the diversity of the users will affect the uses of the system. Therefore, multi-disciplinary knowledge will be needed for an understanding of the user-centered design concept, considering a particular group of inhabitants. The relations between these principles are illustrated in Figure1-2 below:

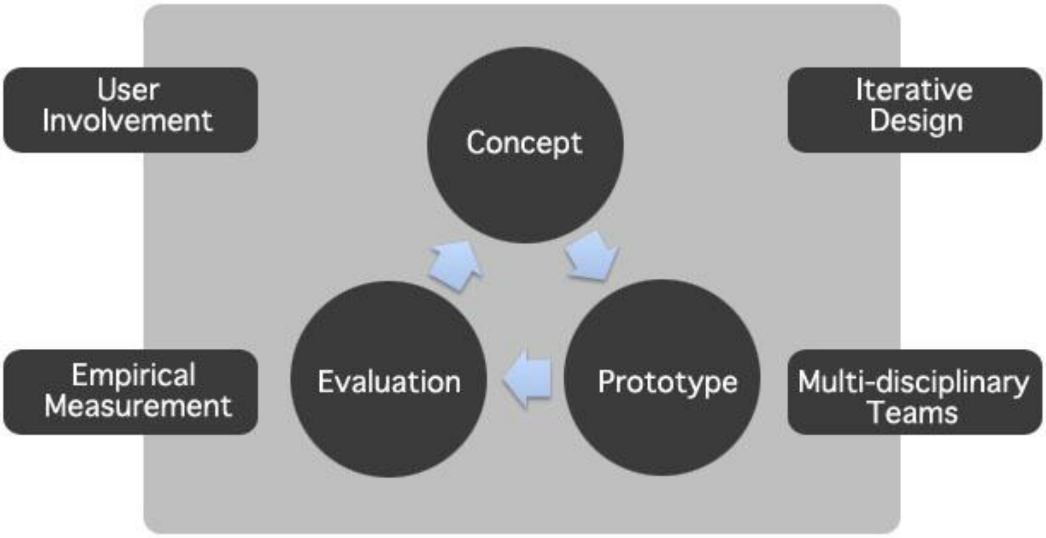

Figure 1-2: User-centered design relation model ***(Marzano and Aarts 2003)***.

1.1.5 SUMMARY

In relation to object-oriented design and other software engineering design concepts, computer applications designed for enterprises or critical situations have learned from design studies and studies from other fields. The user-centered approach will be the focus of the next cross-domain/disciplinary studies, which will incorporate both design expert knowledge and computational research. Furthermore, with the increasing complexity of the PC industry, cross-disciplinary researches will be the key advantage in developing advanced appliances or products in the next centuries.

1.2 Scope and limitation

This research has three limitations:

1. To reify the interface, realization is important. Within the given resource limitations, there can only be one realization for a complex framework.

2. Since there are no requirements for the skin of a smart living space, and only one metaphor can be selected, any theme is possible. The theme for this research is “under the water”.

3. The network topology used for this research is client-server, while the most desired topology is peer-to-peer. The main reason for this choice involved the experimental characteristics for exploring visual components needed for this research.

1.3 The Objective

The objective of this research was to develop an interactive framework for an intuitive interface within a smart living space context. The design of this intuitive interface for existing smart living space facilities, and the interface itself, focused exclusively on information/control. Therefore, this research presents a framework for an intuitive interface design for an existing smart living space. Finally, I will show how a system to reify this framework was implemented.

1.4 The Approach

After reviewing the relevant work on interfaces for smart living spaces and context-aware interfaces, I oriented this research and further investigated the interface design issue in smart living spaces. I conducted design experiments to gain insights in order to construct a hypothetical framework, as well as a framework for the design principles used in this research. Furthermore, by implementing the framework, the design principles and computability of the framework were refined and tested.

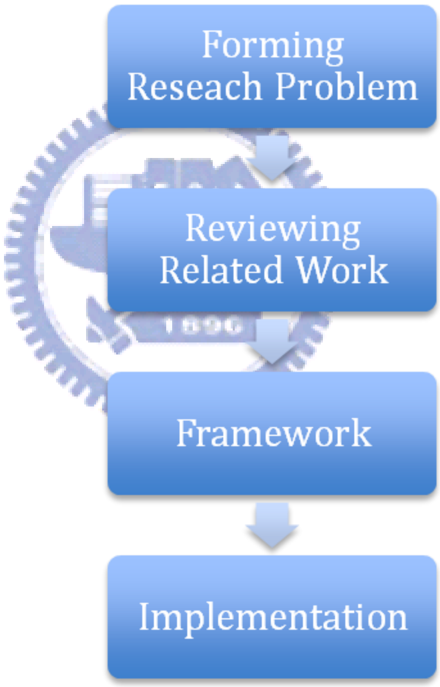

Figure 1-3: Methodology of the research.

The research steps are depicted in Figure 1-3. After formulating the problem, I reviewed relevant projects in fields related to smart living spaces or smart homes. With the lessons learned from this review, I used UCD as a method to explore the intuitive interfaces for a smart living space framework. I then constructed an environment setting with an application and sensor network. Finally, I reified the framework by going through a scenario example.

1.5 Structure of thesis

This thesis is organized as follows:

Chapter 1: The Introduction introduces the research background, scope, limitations, methods and steps, and the structure of the thesis.

Chapter 2: Related Work reviews related projects in terms of smart living spaces, with a focus on interfaces.

Chapter 3: Framework describes an intuitive interface for a smart living space, with a visualization, computation, and information.

Chapter 4: The Skin presents the virtual component, using the "undersea metaphor."

Chapter 5: Implementation reports the construction with buckets, sensors, and actuators.

Chapter 6: Evaluation shows how some experiments were conducted to demonstrate the usability of this intuitive interface.

Chapter 7: The Conclusion discusses the research results.

2

Related Work

The purpose for reviewing related work is to situate our research into a broader research context, to gain insights from previous researches, and to find avenues for further investigation. In this chapter we review related work regarding smart living space projects (2.1) and context-aware interfaces (2.2).

2.1 Interfaces for Smart Living Spaces

While the human-computer interface is an issue in a smart living space, researchers are still examining the traditional input-output relationship, and are searching for a novel transformation into a new design principle (Marzano and Aarts 2003). Humans and machines are independent entities; a human perceives an environmental stimulus and expresses his feelings and reactions to it, while a machine senses an external condition and displays feedback. To make humans and machines work together in a practical way, two important elements are an interface and the interactions between the humans and machines.

The above issues are important for the creation of a smart living space. Therefore, this research involved a review of some smart living space projects in terms of their interfaces.

2.1.1 PROJECT OXYGEN

Project Oxygen is a collaborative effort involving many research activities throughout the Laboratory for Computer Science (LCS) and the Artificial Intelligence Laboratory (AIL) at the Massachusetts Institute of Technology (MIT). The Oxygen vision is to bring an abundance of computation and communication within the easy reach of humans through the natural perceptual interfaces of speech and vision so that computation blends into peoples' lives, enabling them to easily do the tasks that they want to do – collaborate, access knowledge, and automate routine tasks and their environment. (Figure 2-1)

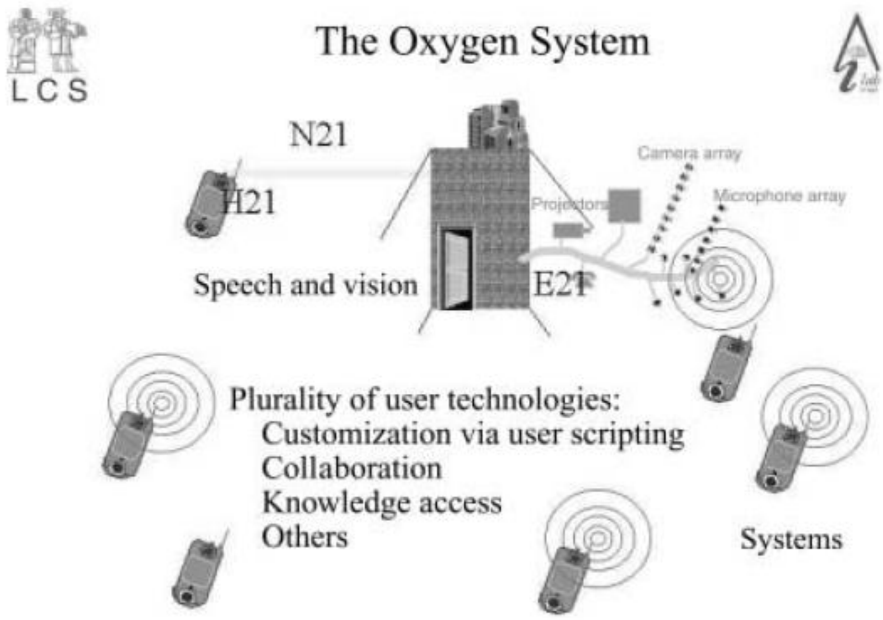

Figure 2-1: An overview of the Oxygen Infrastructure (MIT Project oxygen).

Oxygen's Software, which adapts to changes in the environment or in user requirements (O2S), helps people do what they want, when they want to do it. But all of the information is not together and is too messy. The software can also use speech control. However, as of now, speech recognition technology is not yet mature. So mistakes are easily made.

2.1.2 THE AWARE HOME

The Aware Home has two identical and independent living spaces, each consisting of two bedrooms, two bathrooms, one office, a kitchen, dining room, living room, and laundry room. In addition, there will be a shared basement with a home entertainment area and a control room for centralized computing services (Figure 2-2).

Figure 2-2: One of the Aware Home applications (Aware Home Website).

The Aware Home focused on technologies to accomplish four things: (1) to assist seniors as they age in place; (2) to support the communication and coordination tasks of formal and informal caregivers; (3) to simplify the management of the home and its myriad activities; (4) to provide much needed assistance for individuals at risk and the busy family members who care for them. The system uses sensors installed throughout the house. The distributed operation environment and network assess the indoor situation by sensing and actively identifying the occupants (including status, position, activity, posture, expression, sound). This system has as its goal assisting caregivers with communication tasks and in caring for the security and health of elderly occupants.

2.1.3 SMART ARCHITECTURAL SURFACE

The Smart Architectural Surface (Chang, et al. 2004) is a highly integrated planar construct for diversified smart home services. It uses networked smart cell units equipped with various sensing, cognition, and actuation capabilities that would allow run-time polymorphism as the basis for functional changes for various event-driven operation scenarios. The SAS system can demonstrate collective intelligence outcomes that are mediated by various multi-modal interactions. The key applications currently being developed for the SAS system include Dynamic Wallpaper, Digital Calendar, Digital Mirror, and a Context Aware Videophone (Figure 2-3).

Figure 2-3: SAS surface Demo (Chang, 2004).

SAS would show coordinated intelligent behaviors by utilizing the computational power distributed throughout the participating smart cell units. The SAS system transforms into different run-time objects to accommodate various functionalities by simply changing the digital states of its components.

2.2 Context-aware Interface

Context-awareness becomes an important design issue when building human computer interactions. Context awareness involves when things will happen, what activities are being performed, and why those actions occur as they do (Abowd and Mynatt 2004).

According to this definition, context may be anything that describes the situation of the user, like the logical or physical position of the user, the current weather, or even the mood of the user, as long as it is relevant to the current application or the interaction with it.

Some researchers (Dey, et al. 1999, Gross 1998, Leonardo, et al. 2005) have seen context as anything that may be used to adapt a user interface to the current needs and situation of the user. The device capabilities of the user interface also need to be adapted to improve its usability. Thus the device capabilities are relevant to the interaction between the user and the application and can be seen as context attributes.

2.2.1 NEBULA

Nebula (Marzano and Arts 2003) is an interactive projection system designed to enrich the experience of going to bed, sleeping, and waking up.

Through simple body movements and gestures, it provides an intuitive and natural way of physically participating in a virtual experience. There are four main functions in Nebula. First, by placing a smart ‘pebble’ containing interactive content into a bedside ‘pocket,’ you can change the ceiling’s interactive projection theme or topic. Second, by setting the alarm clock, the system projects two dots onto opposite sides of the ceiling. Third, you can write a note or sketch something on a piece of paper and place it underneath the alarm clock. Then the note or illustration will be projected on the ceiling. Finally, pebbles can also contain games. Figure 2-4 shows some examples of this system.

Figure 2-4: Nebula with reconfigurable ceiling projection (Royal Philips Electronics Website).

2.2.2 AMBIENT AGORAS

The major goal of the Ambient Agoras project (Thorsten Prante 2004) was to transform the physical envelop of a work environment into a social architectural space. It supports informal communication, collaboration, and social awareness within an organization. The Hello.Wall (Thorsten Prante 2004) is an example of this project. It is a remote collaboration within a larger organization.

Figure 2-5: Informal communication around Hello.Wall

The Hello.Wall contains three different interaction states: Ambient, Notification, and Interaction, and is activated by a user's proximity to it (Figure 2-6). When someone keeps his distance from the Hello. Wall, it appears to be an atmospheric decorative element.

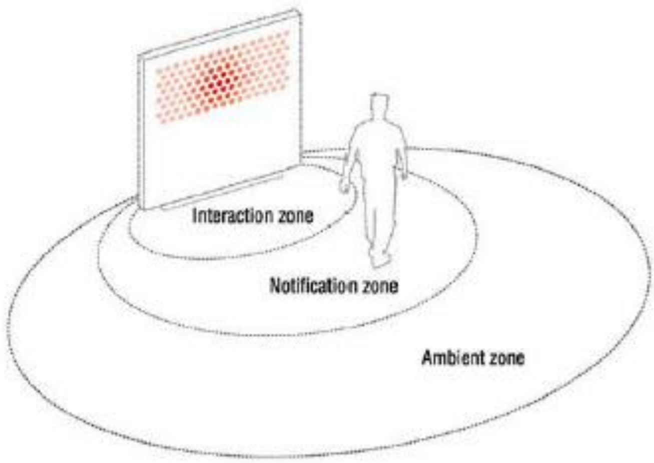

Figure 2-6 Ambient Agoras with three interaction states

2.2.3 SMART KITCHEN

Smart kitchen researchers (Leonardo, et al. 2005) designed and built a series of discrete context-aware interfaces and systems to monitor and provide information about the most commonly performed tasks in a residential kitchen. Kitchens are natural candidates for augmented reality interfaces because there is a high need for users to remain in contact with physical reality while using a number of advanced tools that benefit from digital information (Gross1998).

Five systems were designed to collect information from the environment. These include a FridgeCam, RangeFinder, Augmented Cabinetry, heatSink, and Virtual Recipe (Figure 2-7).

Figure 2-7 Augmented Reality Kitchen: (1) information projection on the refrigerator; (2) the range; (3) the cabinet; (4) the faucet; and (5) drawers.

This research developed a context-aware interface to help enhance the kitchen experience. Moreover, the researchers proposed that the projection of digital information onto the objects and surfaces of the kitchen could increase user confidence.

3
Framework

With the lessons learned from the previous chapter, this research proposes a framework called "ubiquitous co-existing spaces" (uCoS) to explain an intuitive interface for a smart living space. The framework proposed is comprised of virtual (shown in 3.2) and physical frameworks (shown in 3.3).

3.1 Ubiquitous co-existing spaces

Ubiquitous co-existing spaces (uCoS)(Figure 3-1) have three divisions: Visualization, Computation, and Information. The information division provides input from physical sensors and virtual information, such as web services, to the computation division.

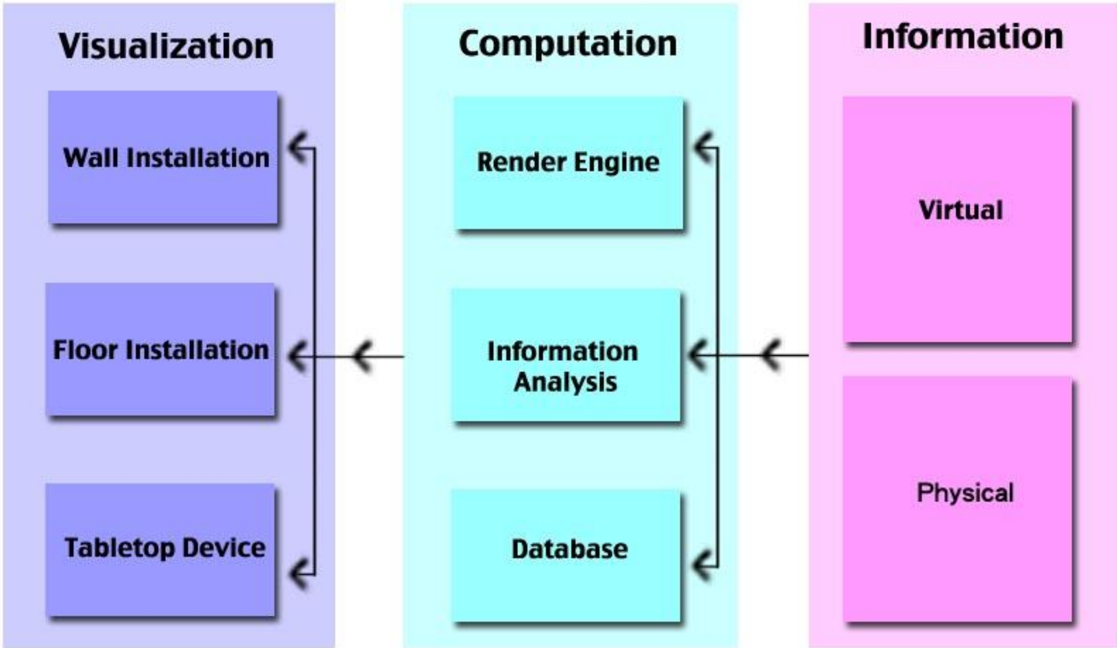

Figure 3-1: Co-existing interactive spaces

Then, with built-in computational mechanisms (which will be explained in the later section), the computation division supplies analyzed data and triggers for the visualization division to display. The main interaction lies in the visualization and information divisions, and each will require heuristic knowledge that will be stored in the computation division (Figure 3-2).

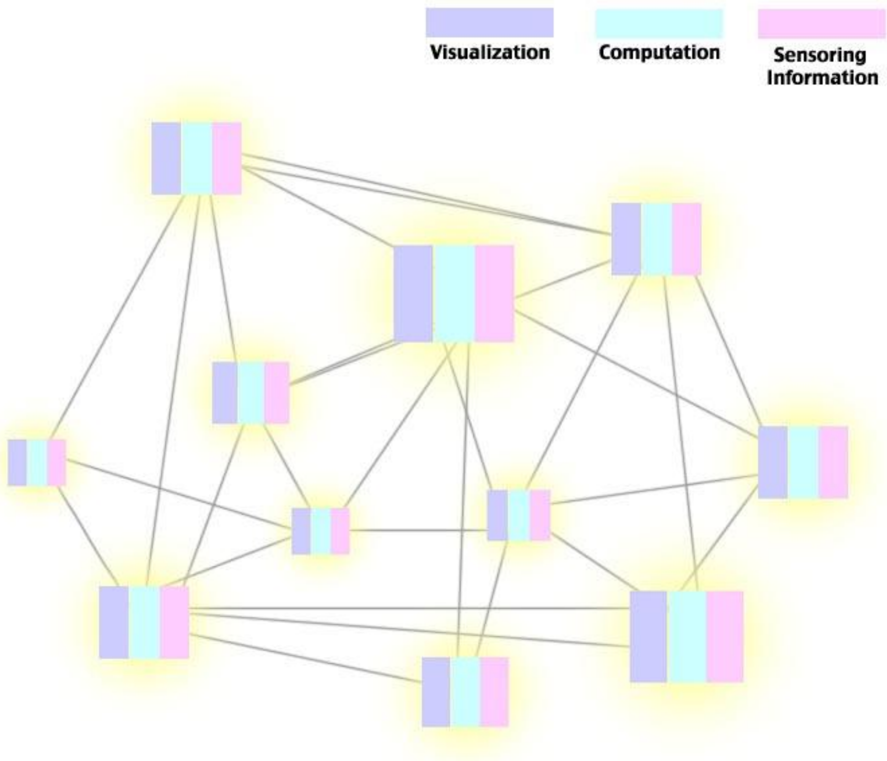

Figure 3-2: uCoS network

The visualization division has at least three components: Wall installation, Floor installation, and Tabletop device. The computation division has three components: Render Engine, Information Analysis, and Database. The information division only has two components: Virtual component and Physical component.

3.2 Virtual framework

One part of uCoS is virtual, which becomes the virtual framework described in this section. The virtual framework (Figure 3-2) depends primarily on the net, the web server. For example, Really Simple Syndication (RSS) is the virtual information that will supply the metaphor data. The data needs to be collected and stored in a particular format in order to be retrieved later for representation. Without realization or analysis, the data is not readable or approachable by common users. Therefore, the system needs a special channel to deal with this special type of information.

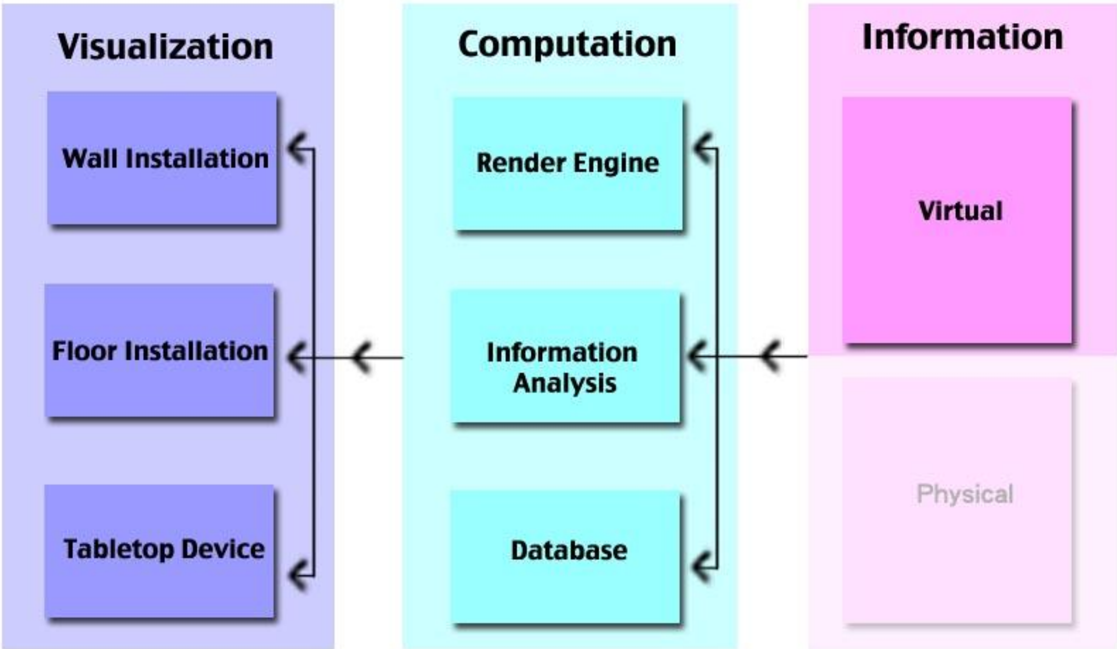

Figure 3-3: Virtual framework

3.3 Physical framework

The other part of uCoS is physical, which becomes the physical framework described in this section. The physical framework (Figure 3-3) primarily depends on the sensors and actuators. As an example, noise can be used as the physical information to represent the metaphor data. Another example is that a user can manipulate a virtual object and cause a physical object to be triggered. The data needs to be collected and stored in a particular format in order to be retrieved later for representation.

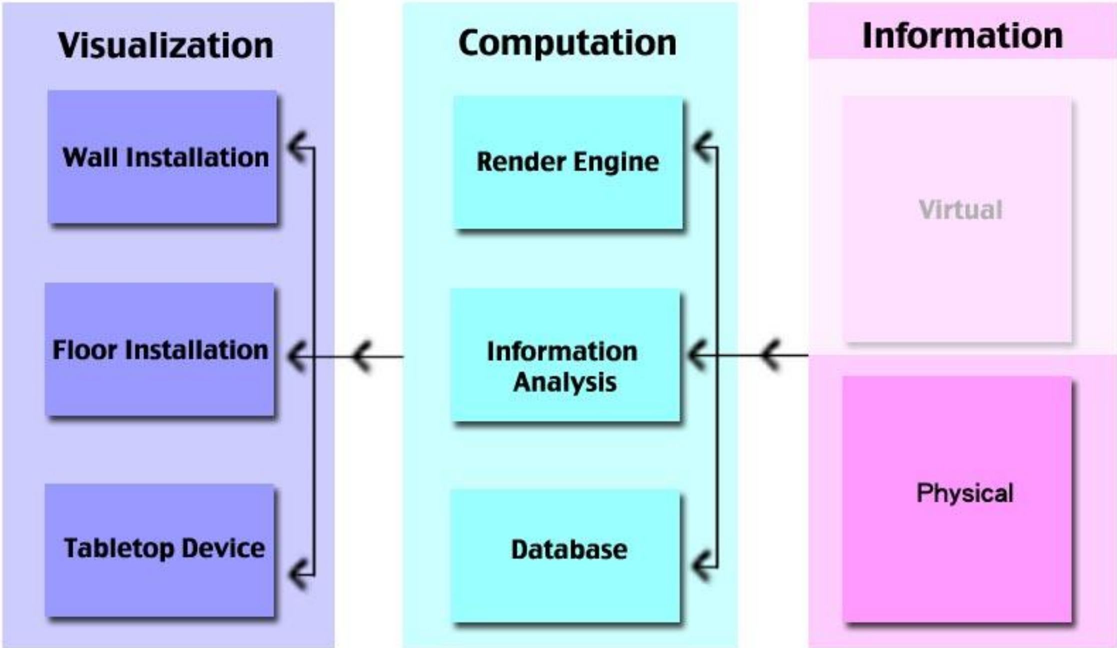

Figure 3-4: Physical framework

3.4 Replaceable skins

In the visualization division, realization lies in the physical space itself, which depends on the context in which the design is located. For example, a wall/floor installation or a tabletop device can consist of three possible components. Each form has its own operations and tangible control activities depend on the context.

The information flow starts with sensing information gathered from external sensors or real-time online streams. This sensed/streaming information flows into the computation division, which contains knowledge logic, as well as memory storage, where the information can be stored for later retrieval.

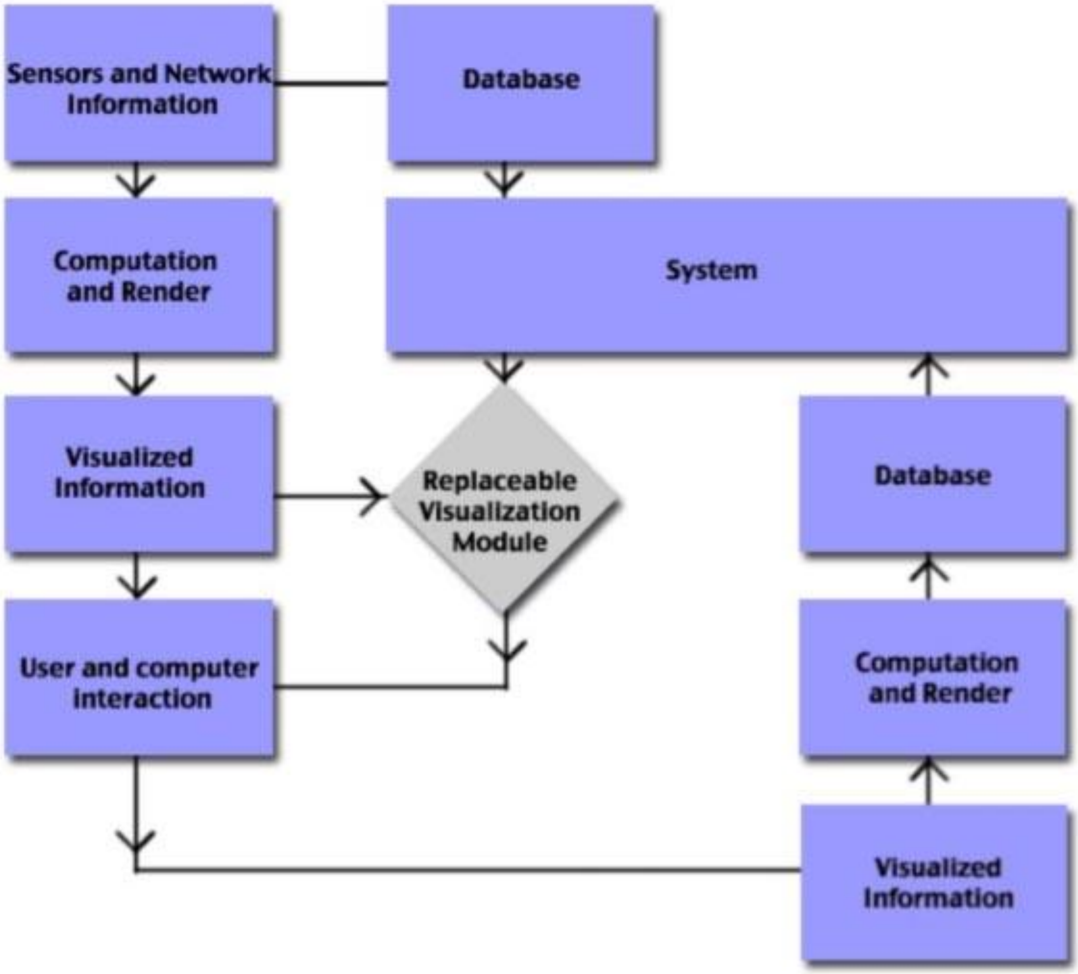

Figure 3-5: System flow chart

The system flow chart shows that information flow starts with the environmental sensors and network information, which the main engine receives the information that will re-appear the form to demonstrate **[Note: See Editor's Note #1.]** (Figure 3-4). The system may also employ a touchscreen to enable user interaction. The visualization module can be replaced by visual effects or other presentation methods.

3.5 Ubiquitous intelligence space

Ubiquitous intelligence space means that this system may permit the free distribution of information under the home environment. Simply speaking, if we consider visualization, computation, and information as one system, we can put this system into every space. Therefore, we can share or send information to every single room in which we live. For example, if someone leaves a message in the living room, the system will add a fish. The fish can "swim" to another room. So someone can receive this message in another space.

4

The Skin

In this chapter, I present the skin design concept (shown in 4.1) and the design components (shown in 4.2). The underwater theme used in this research is a metaphorical means of representing or visualizing the information flowing from web services and the physical sensors in the living space.

4.1 Design concept

Digital media design has brought new and vivid forms of visual experience to people, especially in relation to 3D virtual worlds, which have been strongly influenced by 3D video games and 3D animation. On the other hand, an intelligent building or smart living space is often regarded as one where essential but boring information about the building provides "smart" support to its inhabitants. Of course, the term living space has another meaning—a "liv(e)" + "ing" space, a space that is itself actually living. This means the space, using its own intelligence, can deal with the dynamic activities of its inhabitants.

The undersea theme used in this research is a metaphorical means of representing or visualizing the information flowing from web services and the physical sensors in the living space. With this underwater metaphor, the virtual space is represented by an undersea scene and the creatures swimming through it. As shown in the systems reviewed, the ambient design has to be passive and intuitive to allow effortless interaction. Therefore, the main criteria for designing the behaviors of the creatures were that they had to be natural and immersed in the underwater scene.

4.2 The skin design

With the information above, this research applied the proposed intuitive interface design process and the frameworks in 3.2. The result was a physical device with both physical and virtual components. I called the skin GAIA (GAIA, Gaia the Ambient Interactive Atmosphere).

GAIA has had one realization as a contextual interactive skin. It is reconfigurable and placed over the contextual building information, based on sensors/actuators, wireless sensors-network, and 3D information visualization technologies. A systematic diagram of this skin is shown in Figure 4-1.

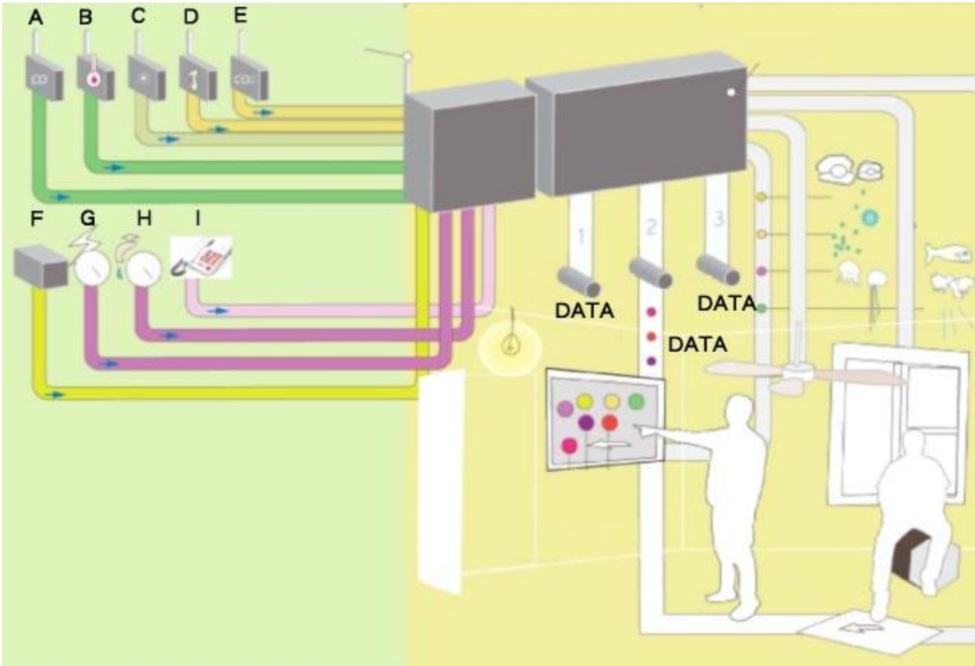

Figure 4-1 A systematic diagram of the skin. The information is (A) CO, (B) Temperature, (C) Illumination, (D) Weather Forecast and UVI Forecast, (E) CO_2, (F) News RSS Reader, (G) Light Switch, (H) Water Sensor, (I) Incoming Call.

The left part of the diagram shows the information division based on the framework mentioned in a previous chapter. The right side of the diagram shows the visualization division. This part represents the data from the information division.

I am responsible for the visual interaction and co-existing spatial context design of GAIA. Because of the physical/virtual context and interaction of the intuitive interface, this system represents a different concept than that of the current interface.

4.3 Design components

To focus on this particular scenario, a list of commonly used information available in a typical smart living space was collected. Table 4-1 shows this information.

Table 4-1: The relationship between Information and Computation

Information	Computation
Illumination	Sensor with Database
Temperature	Sensor with Database
CO_2	Sensor with Database
CO	Sensor with Database
Weather Forecast	Real time updated Web service
UVI Forecast	Real time updated Web service
Timer	Real time updated Hardware clock
News RSS Reader	Real time updated RSS feeder
Incoming Call	Phone signals
Water Sensor	Integrated System
Door Opener	System computation actuators
Light Switch	System computation
Welcome Effect	Database computation

5 Implementation

This chapter presents the physical component design, including the room, sensors, and actuators. Virtual components (GAIA interface) are also presented. Finally, two examples are described to show how the system works.

5.1 Physical Components: A Room

I took advantage of the bucket **[Note: See Editor's Note #2.]** as the building material for the room. This kind of bucket has a lot of functions. First, because I use "under the sea" as a metaphor, the bucket can be pictured as a bubble. Second, since buckets are used as wall units, sensors and actuator can be easily hidden. Finally, buckets provided extendibility and adjustability in constructing the room.

5.1.1 THE CONCEPT: BUBBLE AND FRAME

The room was designed as a group of bubbles with a frame surrounding them (Figure 5-1). There were two reasons for using bubbles: the underwater theme and the modular construction material. With the modular floor boxes and the surrounding bubble box, the sensors and intelligent construction could be installed and experimented with within the components.

With one entry and one window, the screen was located on the right side when facing the window from the entry. This left two corners—one at the right when facing the window and the other containing the boxes for storing the sensors and wireless devices. The sofa **[Note: See Editor's Note #3.]** was beside the window while the floor visualization component was in front of the sofa.

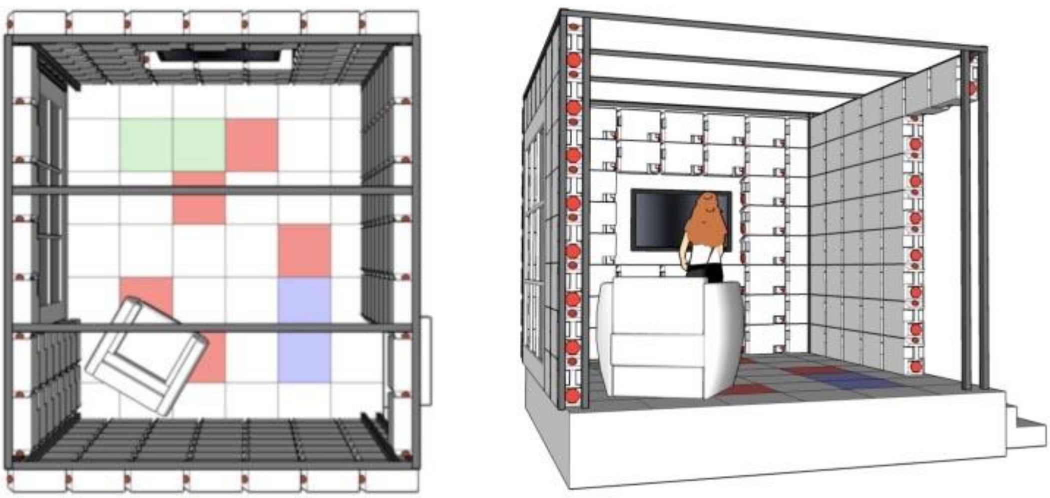

Figure 5-1: Smart living space simulation picture

The main construction used metal frames connected to a wooden floor. The concept of a frame was used both symbolically and as an actual construction method (Figure 5-2).

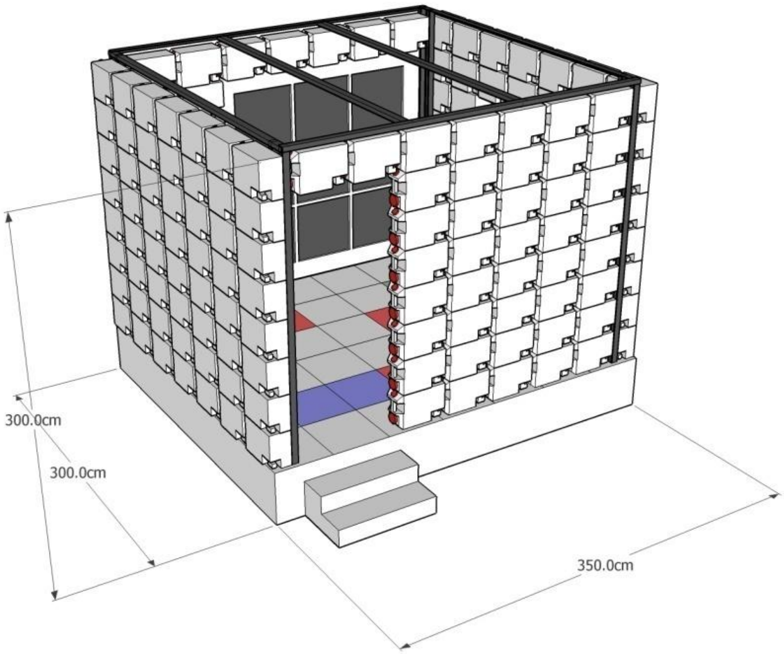

Figure 5-2 Scale of the smart living space

5.1.2 THE WALLS AND CEILING

The walls contained sensors and lights, and the bubbles **[Note: See Editor's Note #4.]** were used for their construction (Figure 5-3). The ceiling was a reflection of the hard and soft parts of the room. We used fabric as a filter for the light and to soften the edges of electronic devices, as well as for a place to install sensors.

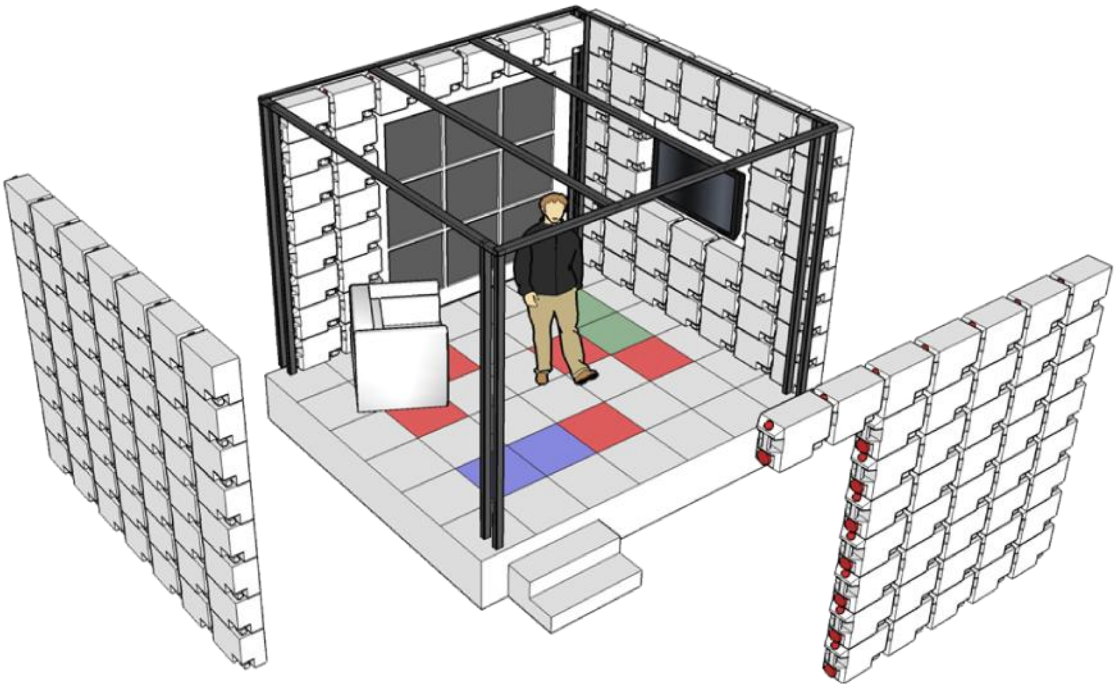

Figure 5-3: The walls and ceiling

5.1.3 THE SENSORS

The sensors that were used to test the implementation were divided into four types. One was a water sensor as shown in Figure 5-4(A). The water sensor had three main tasks: gathering incremental consumption information, gathering concurrent consumption information, and acting as a trigger to send information back to the computation division. The second was a CO_2 sensor, as shown in Figure 5-4(B). The CO_2 sensor sensed the CO_2 quantities in the space and sent them directly to the computation division. Third was an illumination meter, which gathered the illumination data within a particular area. This meter is shown in Figure 5-4(C). The last was a CO sensor, which is shown in Figure 5-4(D). The tasks and operation of the CO sensor were similar to those of the CO_2 sensor.

These sensors were used to gather raw and real data from the actual environment. Therefore, each sensor required a different operation and programming according to the API and each sensor's individual specifications.

Figure 5-4: Sensors. (A) Water sensor; (B) CO_2 sensor; (C) Illumination sensor; (D) CO sensor.

5.2 The virtual components

These were used for the visualization of the undersea metaphor. They included power consumption, water consumption, a fish clock, thermometer, CO alarm, CO_2 alarm, answering machine, phone buzzer, party dancer, light switch, window switch, weather crystal, and RSS reader (Figure 5-6). The prompt words did not normally appear. But if you forgot what kind of information a virtual object represented, you could touch the treasure box and the prompt words would show up.

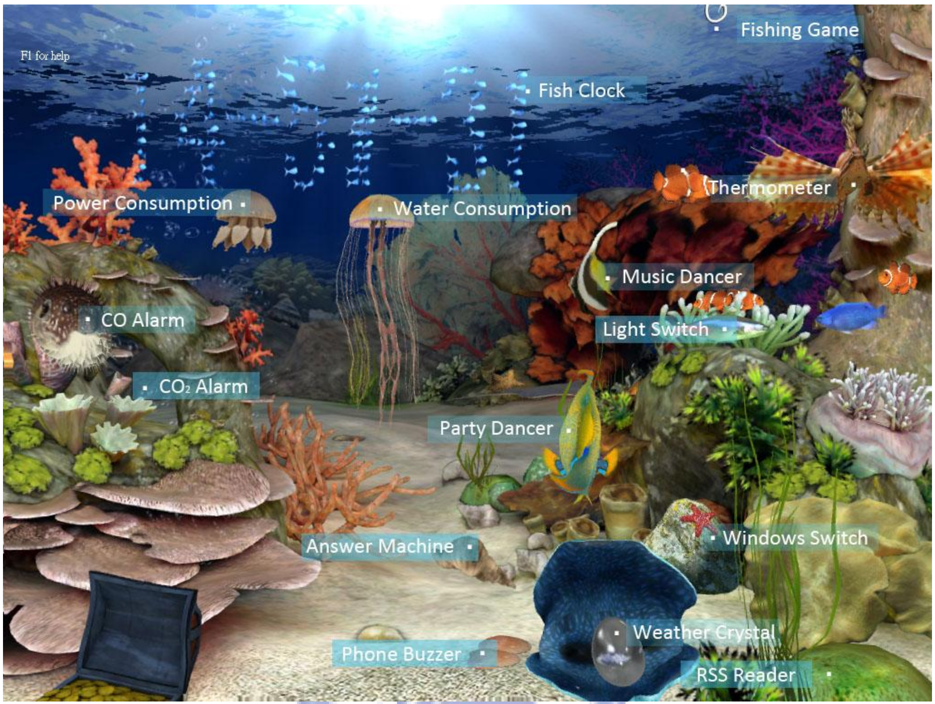

Figure 5-5: The GAIA interface with prompt words.

5.3 Integrated skin

In this section, I propose two examples to show how the system works. The first one involves weather information. The second one involves power consumption information. Both are represented by virtual components of the co-exiting framework.

5.3.1 AN EXAMPLE: WEATHER TASK

In Figure 5-7, the weather information passes from the left to the right side. By passing through the computation division, the weather information will be stored in a database and analyzed. The user interacts with the system and the visual effect in the visualization division changes. For example, when the system grabs the weather information from the Internet, a user can select the area where he lives. The system then displays the weather information for that area.

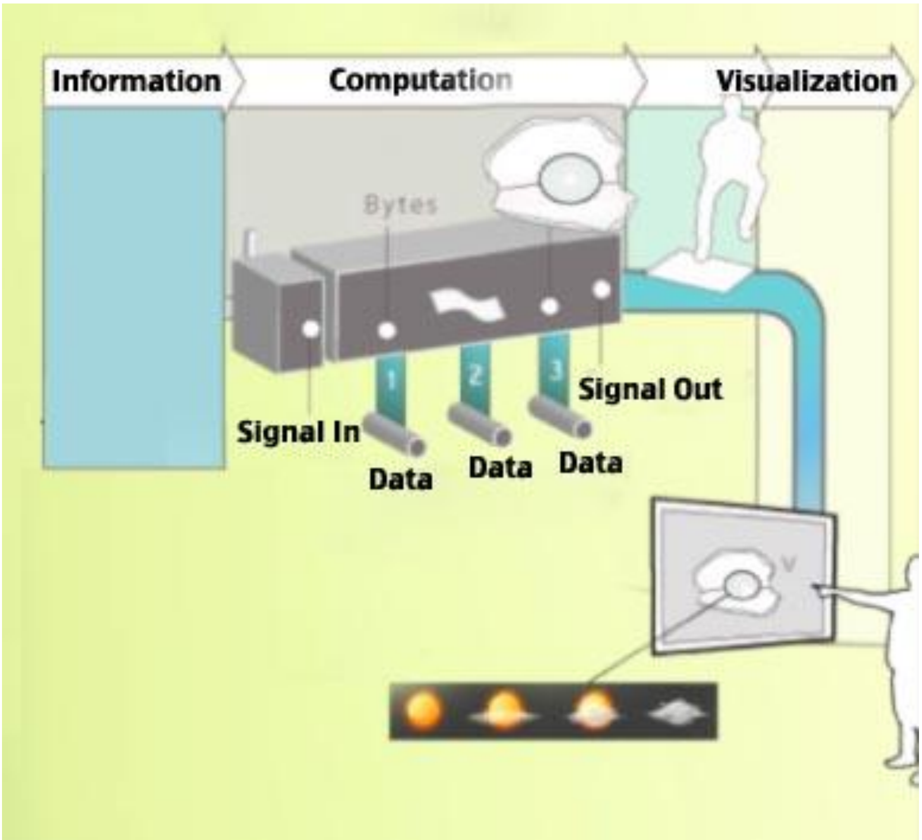

Figure 5-6: Weather information in GAIA

5.3.2 AN EXAMPLE: POWER CONSUMPTION TASK

In Figure 5-8, power information from the left comes into the database component of the computation division. However, the information has a connection with the virtual jellyfish object.

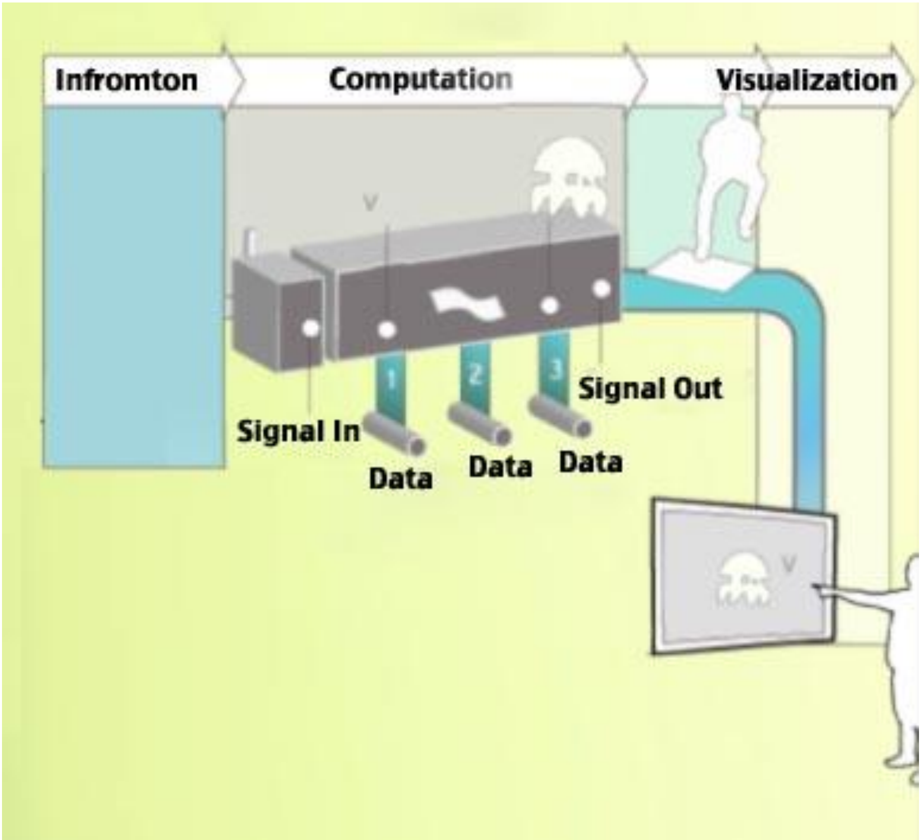

Figure 5-7 Power Consumption information in GAIA

6 Evaluation

This chapter discusses the reification and evaluation of the implementation solutions. The main evaluation involves user testing with tasks. While the main purpose of this research is to explore the possibilities of an intuitive interface for smart living spaces, the implementation and framework of such an interface are the two main subjects of this research. Therefore, this discussion of the reification will focus only on tasks that users might confront in the developed room.

Usability testing will be described in 6.1, and tasks and user evaluations will be described in 6.2, along with tables documenting the experiment results.

6.1 Usability testing

There were three important criteria **[Note: See Editor's Note #5.]** that were evaluated in the co-existing interactive space implementation: Time and

Efficiency. Time is a typical measurement in usability studies, and a typical metric for target system performance. Efficiency means the rate or speed at which an interface enables a user to accurately and successfully complete a task. While a faster response time is usually better, consistent response time is also important. Therefore, I used the task analysis approach to define the task and the goal of the task, and then to list the steps involved.

6.2 Task

Task analysis is a method that evaluates how people actually accomplish things with software. Through observations and interviews with users, an analyst determines a set of goals belonging to the target user. Then, a set of tasks that support these goals is determined. With this in mind, we can describe the relationships between tasks and goals in our system (Table 6-1).

Table 6-1: The relationships between tasks and goals.

NO	Task	Goal
1	Weather Forecast	Recognizing forecast information
2	Location of Lion Fish in the frame	Recognizing temperature
3	Typesetting by Fish	Recognizing time
4	Push-moving by Starfish	Actuating the physical device
5	Light trigger by light fish	Actuating the physical device
6	News in bubbles word by word	Recognizing real time news
7	Touch-follow game	Basic operation
8	CO sensing trigger and transformation of fugu	Recognizing CO warning
9	Jumping activity of shell	Incoming call display
10	Recording within conch	Answering machine operation
11	The size and vibration speed of	Recognizing water/power

	jelly fish	consumption information

The detailed tasks are described below:

1. Weather Forecast

   Stanley has a date with his ex-girlfriend in the afternoon. He wonders if he needs to take his umbrella. Please help Stanley to find the weather forecast information in this system.

2. Location of Lion Fish in the frame

   On a very hot day, Stanley is watching the television in the living room. He wonders what the temperature is now. Please help Stanley to find the temperature information in this system.

3. Typesetting by Fish**[Note: See Editor's Note #6.]**

   Stanley roasts a potato in the kitchen. After 10 minutes, he will have a delicious meal. He wants to know what time it is now. Please help Stanley to find out the time information in this system.

4. Push-moving by Starfish**[Note: See Editor's Note #7.]**

   Stanley is reading in the studio. He wants to open the window and take a nap. Please help Stanley find out how to open the window with this system.

5. Light trigger by light fish

   Stanley has just come out of the studio. He comes to the living room to read the newspaper. But, he forgot to turn off the light in the studio. Please help Stanley to find out how to turn off the light with this system.

6. News in bubbles word by word

Ma Ying-Jeouis is going on a long trip in two days. Stanley wants to read this news. Please help Stanley to find out how to read the news with this system.

7. Touch-follow game

Stanley bought a new smart living digital frame. It's looks like sea world. Please help Stanley to find out which fish are interactive when you touch them in this system.

8. CO sensing trigger and transformation of fugu

The kitchen has now filled with CO. Please help Stanley to find out which fish can warn you with this system.

9. Jumping activity of shell

Stanley is listening the music. At this moment, he has a phone call. Please find out which fish can alert you when you have a phone call with this system.

10. The size and vibration speed of the jelly fish

Stanley comes home. He then turns on the air conditioning. Please find out which fish provides feedback in this system.

11. Recording within conch

Stanley wants to tell his mother he loves her. But his mother is always so busy. Therefore, Stanley tries to leave her a message. Please help Stanley to find out which fish can record his voice in this system.

6.2.1 PILOT TEST

The pilot test was for the purpose of verifying whether or not the test itself was well formulated. For instance, a colleague or friend can be asked to participate in a user test to check whether the test script is clear, the tasks are not too simple or too hard, and that the data collected can be meaningfully analyzed (Table 6-2). I averaged the time that experts and novices finished the tasks.

Table 6-2 :The Pilot test Results

Task completion time (second)	Expert	Novice	Average
Task1	15.49	50.21	32.80
Task2	89.34	203.32	146.33
Task3	5.32	10.29	7.80
Task4	18.93	50.11	34.52
Task5	25.2	30.21	27.70
Task6	57.32	90.03	73.67
Task7	3.91	8.93	6.42
Task8	6.32	15.89	11.10
Task9	7.48	14.56	11.02
Task10	9.23	18.56	13.90
Task11	11.27	22.98	17.13

6.2.2 RESULTS

This experiment was performed at the SOFT Lab, National Yunlin University of Science and Technology, with six participants and a duration time of 30-

40 minutes. The environment was the bubble room described above with the proper setting for a smart living space.

Table 6-3: Result table

Task completion time (second)	User1	User2	User3	User4	User5	User6	Average
Task1	8.34	10.21	5.23	20.31	20.2	5.23	11.59
Task2	30.3	23.23	50.23	30.98	35.90	45.11	39.95
Task3	3.22	5.32	12.30	5.32	18.45	8.39	8.83
Task4	10.33	30.72	21.32	32.45	16.32	4.21	19.23
Task5	15.76	20.74	36.69	17.38	17.23	10.30	18.68
Task6	20.47	20.34	19.34	48.23	19.98	22.76	25.19
Task7	3.09	4.23	3.45	4.23	2.43	5.32	3.79
Task8	6.32	4.26	8.93	15.89	18.32	8.32	10.34
Task9	12.4	10.20	9.56	8.29	5.20	8.83	9.08
Task10	8.22	5.37	5.26	9.22	13.28	8.45	8.30
Task11	8.27	12.21	7.28	5.43	12.53	7.45	8.03

6.2.3 SUMMARY

As the results show, the GAIA interface successfully combined virtual and physical information in an undersea metaphorical environment. You can see from the results table that the task completion times became shorter and shorter. Therefore, I can declare that the GAIA interface was learnable and efficient.

7
Conclusion

This research developed a framework called ubiquitous co-existing spaces (uCoS) for a smart living space, while simultaneously presenting a room embedded with sensors and actuators. uCoS provides an additional networking framework on top of a co-existing framework. uCoS further describes a way to embed interaction within the context of smart living spaces.

The implementation developed by following the uCoS concept showed a real time virtual space as well as associated physical components. By experiments and pilot studies, the intuitive interface design process, as well as its implication, was shown as the final result of the research. Furthermore, through usability evaluations, the intuitive behaviors were found and can be iteratively incorporated into the design. The user-centered design process has shown its impact and can be used to sustain the developed result.

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