Developing Intelligent Smart Home by Utilizing Community Computing

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Abstract. In Ubiquitous environment, system makes their own decision without or with minimized user interaction to provide required services to users. To fulfill this requirement the system needs to collect the proper information of surroundings and define how to react to the changes based on found information autonomously. To achieve this process, the system should equipped with three basic components which are sensing infrastructure, context aware or intelligent decision, and smart services. Main purpose of this research is how to enable this process efficiently and suggest the way of developing smart space. In this paper, we present ***Community Computing*** as the method of developing smart space and three components are briefly described. Also, three applicable scenarios and problems that might be happened at smart home are suggested and how community computing can be utilized to solve these problems is shown.

Keywords: Ubiquitous, Smart Home, Community Computing, Intelligent Service, Sensor Network, Context Aware.

1 Introduction

Since Mark Weiser [1] stated basic concept of Ubiquitous computing in 1990s, great attention has been paid to the implementation of it. Even though in the early concept of his Ubiquitous computing simply states that user can access and utilize computing power anytime and anywhere easily today's definition of Ubiquitous computing has been changed and evolved according to rapid growth of technology. In the smart environment, the deployed system recognizes user's behavior and does its best to fulfill any service request from user by self-decision. Therefore, recent Ubiquitous computing can be newly defined as *"The system figures out users' intention intelligently with minimized interface with user and makes their own decision such as what type of service provide and how to provide to users based on specific situation."* By considering this definition, the main critical factor of implementing

H. Ichikawa et al. (Eds.): UCS 2007, LNCS 4836, pp. 59–71, 2007.

the Ubiquitous computing is that "*Defining Specific Situation and Providing Services Intelligently"* Most all of the services are strongly depend on the situation and only well defined situation enables the system to provide the right services to user. Therefore, finding or defining of current situation plays critical role in Ubiquitous computing environment. The Ubiquitous computing system collects information or context, analyzes the given information, and makes their own decision to provide best services to users with or minimized interaction with them. For that reason, all of the Ubiquitous services are provided based on the situation around users and situation-aware is the starting point of providing services. In the recent year, numerous studies have attempted to find and explore field of situation-aware and situation based services [2][3][4]. To achieve this goal, the system should have or acquire fair amount of rich information in the environment. Since the user interface in the Ubiquitous environment is minimized or even disappeared acquiring user's intention or defining situation is quite limited and not an easy task for the system. However, the system still needs to figure out current situation to make right decision for providing satisfaction to users. To overcome this problems the sensors and sensor network has been researched on broad area [5][6][7][8]. The sensors or sensor network emerged from the question: "How can we collect the accurate information automatically without perception and effort of human?" More to the immediate point, sensing information which collected from sensor network is basic and critical factor of situation-aware. After collecting the environmental information through the sensor network the system should define their own decision that what's the current situation is. As a result, we need stable method of developing smart space and we develop the Community Computing which is new computing paradigm for coming Ubiquitous computing era. This solution provides the method of defining current situation based on the given sensing information and trigger the appropriate services through creating service community. Finally, more advances service is needed to satisfy the requirement of Ubiquitous environment. In this paper, we describe the concept of Community Computing is and how it works. Also, the factors that required developing smart space is suggested in detail such as sensor infrastructure. Finally three problem scenarios of smart home are given and how we solve these problems by utilizing Community Computing are described.

2 Smart Homes and Services Examples

In this section, we introduce two different smart homes briefly and selected services from different organizations.

2.1 House_n Project from MIT (Massachusetts Institute of Technology) [9]

The MIT develops real living test bed for smart home which is called *Place Lab* and conducts research on Ubiquitous services. They developed their own sensing devices and deployed them at their test bed. One of their projects is developing sensor

Fig. 1. The inside of Place lab with the sensing devices

network kits for low cost and easy installation. In this project, any volunteer can join this project and live there for a while and researcher can conduct their study with acquired data through these sensors in the place lab.

They can measure the physical and sedentary activities of user in the place lab through deployed sensor networks. From acquired sensing data, they can define the Activities of Daily Living (ADL) and provide the Ubiquitous services. They also research on way of developing smart home easily and efficiently with industrial construction vendors. Figure 1 shows the inside of place lab and deployed sensor devices at place lab.

2.2 Aware Home Project from GIT (Georgia Institute of Technology) [10]

The GIT also develops its own two stories of smart home which is called Aware Home as the research result of the Aware Home Research Initiative (AHRI). They define four main research categories of smart home "Design for People", "Technology", "Software Engineering", and "Social Implications" They are working on developing smart home services and most of services are based on the context aware technology by utilizing the sensing information. For example, indoor location service, Activity Recognition, Context Aware Computing, Automated Capturing of Live Experience and so on. The test bed (Aware Home) is also living test bed to provide real research data. Figure 2 shows the blueprint of Aware Home with its appearance.

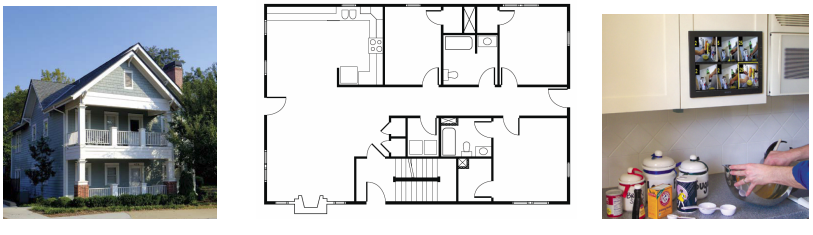

Fig. 2. Picture of Aware Home and Cook's Collage Service

In this smart home, they also equipped with multi-type of sensors. For example, the kitchen has vision sensor and aids the process of cooking with tracking user's behavior as shown in figure 2.

3 Newly Proposed Smart Home

The CUS (Center of Excellence for Ubiquitous System) has also researched on the smart home (hereinafter CUS smart home) since middle of 2003 to provide comfortable and easy wellbeing life to users for coming Ubiquitous era. This chapter mainly focuses on the three components of developing smart home as stated earlier such as sensing infrastructure to get context information, method of making decision with collected sensing information and problems and answers that can be resolved with proposed system.

3.1 Overall Architecture of CUS Smart Home

Overview of CUS Smart Home. The CUS smart home consists of one bed room with one living room. The diverse research result of CUS is installed, deployed and evaluated through this test bed. The main purpose of this smart home is providing wellbeing life to user in Ubiquitous environment through intelligent service which is defined, selected and created by the smart system. To provide Ubiquitous intelligent services, the CUS smart home organizes as three different main components which are sensing infrastructure, intelligent self decision system, and Ubiquitous services. With sensing devices, the smart home is able to collect many different types of context and provide well defined information about home environment. The stable and diverse sensing infrastructure provides basic background knowledge for the intelligent decision making system to able to achieve high quality of situation aware. The intelligent decision making system of smart home which is called Community Computing [11][12] makes its own decisions about *"What the current situation is!"*, "*What type of service should be provided!"* and *"How to provide the services!"* Finally, the digital devices are installed to support the execution and providing of services. Figure 3 shows three steps of proving intelligent service and deployed equipment in the smart home. In this section, we examine three components briefly and suggest the services scenarios that might happen in Ubiquitous smart home.

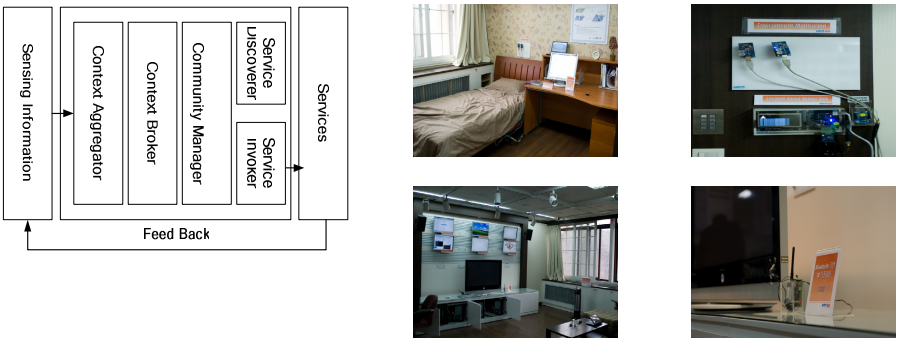

Fig. 3. Three Basic Steps for Implementing CUS Smart Home and Equipped Devices

3.2 Sensing Infrastructure

The sensing infrastructure is basic and inevitable components for Ubiquitous computing and has received much attention in many areas. In this paper, we focus on what type of information is required and how we can get them to support efficient decision through examine CUS smart home. Figure 4 shows the deployed sensors in our smart home.

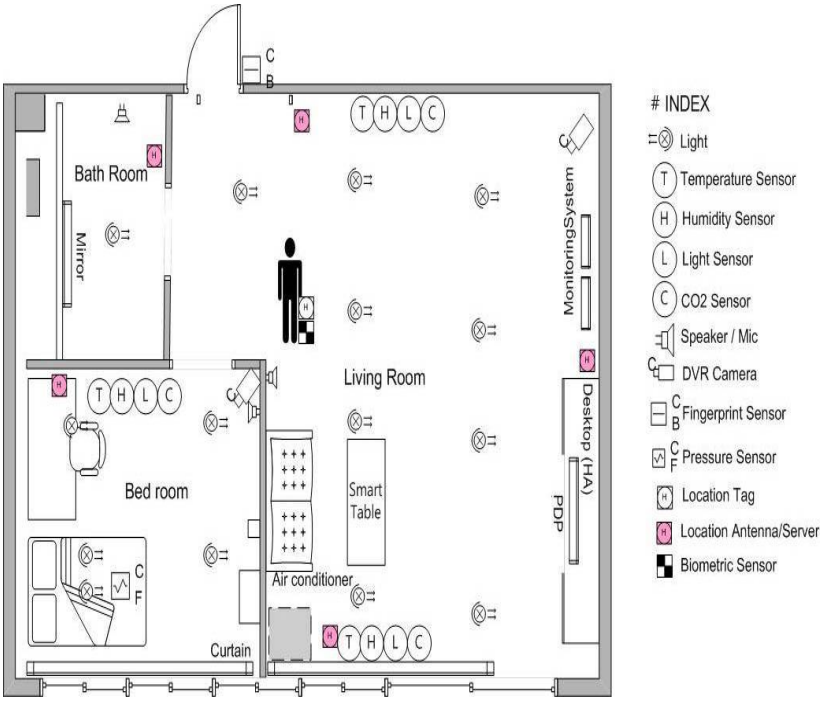

Fig. 4. Sensing Infrastructure of CUS Smart Home

Type of Sensing Information for Smart Home. To define the current situation, the environmental information such as temperature, humidity, light, noise, and quality of air is critical factor in any situation. The CUS smart home deploys these five types of sensing infrastructure and acquires stable information from them. Also, CUS smart home is able to understand the location of each object through two different types of location sensor. The first location system provides area level of location such as bed room, living room or door and the other system provides location of *'cm'* level to support more precise information. Also, we deploy the biometric sensing device to get user's current physical state. This device detects user's body temperature, heart rate, blood pressure and so on. For explicit interface with user in the smart home, we develop mobile home pad to control any devices in the home and monitors the state of smart home with much more easy graphical interface. For authentication of user, the finger print device system is installed at the front door and voice recognition system is deployed. Finally, the home has smart bed which equipped with the 12 touch sensors

on mattress. With these sensors, the system can figure out if user is sleeping in bed or not. We will go over the logic of defining user's sleeping in detail later. Consequently, we deploy 11 different types of sensing device to collect context information. This might not be enough to provide critical information to support making right decision of smart system. We still struggle to provide many different types of sensing information.

Communication Protocol between Sensors and Context Aggregator. Since there is no standard data formation of sensing information each sensor has its own communication protocol and unique data format. To overcome this problem we develop our own data packet formation as shown figure 5. When the context aggregator receives the data from each sensor it converts to given data format and process them.

1 Byte	1 Byte	1 Byte	1 Byte	1 Byte	7 Bytes	2 Byte
0xC8	Length	Sensor Class	Sensor Type	Sensor Id	Timestamp	Value

Fig. 5. Sensing Data Formation of CUS Smart Home

Also, different type of sensor devices utilizes different communication protocol. The environmental sensors utilize the Zigbee protocol as their communication method and the location sensing system also follows the Zigbee protocol. The pressure sensing system of smart bed, home pad, finger print, and voice information provide their information through socket communication either WLAN or Ethernt. When the context aggregator receives the sensing data it stores the information to its own data base through database manager and sends to the context widget to transfer the information to the context broker which defines current situation and make intelligent decision. Finally, Table 1 shows the summary of each sensing information and communication protocols.

Table 1. Deployed Sensing Type and its Communication Protocols in Smart Home

Category	Type	Communication Protocol	Function
Environment	Temperature Humidity CO2 Light Noise	Zigbee	Environmental Information
Location	Area Level cm Level	Zigbee UWB	Location Information
Situation	Pressure sensor	LAN	Sleeping Information
Interface	Home Pad Voice Recognition	WLAN LAN	Device Control
Biometric Information Authentication	Heart Rate Blood Pressure Finger Print	LAN LAN	Biometric Information Authentication

3.3 Situation-Aware and Creating Service Community by Community Computing

The main and critical factor of smart home is that how to define current situation and way to provide the intelligent services to the users. Our smart home defines the situation by utilizing acquired sensing information through the sensing devices. To define the current situation and select best smart services we develop the ***Community Computing Solution.*** Describing community solution in detail is not a purpose of this paper but we present basic concept of Community Computing briefly. In the Community Computing, the definition of Community can be stated as that *"a community is an abstract unit in developing process and a set of computing entities in execution environment for a fusion service"* which means the Community is that a collection of objects which struggle to provide their capabilities to resolve common problems or required services. Also, Community Template provides basic background of creating community as meta-level. By using Community Template the user or developer is able to define service list for specific situation. To setup the goal or which type of service they provide is closely based on defined situation. We develop the ***Context Broker*** which receives the sensing information from infrastructure, analyzes and defines what the current situation is. After defining current situation, the Context Broker reports the situation to the ***Community Manager.*** The main task of Community Manager is that sets up the service goal and creates community according to the given situation. Each devices, human, or any object can join the community if they are able to provide specific service to resolve common goal. Therefore Community Manager should figure out their capability any time and possibility if they can join the community. By creating community, the Community Manager defines the services that each member should provide for achieving common goal. In this process, the ***Service Discover*** and ***Service Invocator*** methods are implemented. In Community Computing, Community has five states of life cycle as shown at Figure 6 and next section describes the concept of each state briefly,

Fig. 6. Five States of Community Life Cycle

Community Life Cycle

Creation is a process to describe community by system designer or developer. The community is described as a language model which contains a goal description, relation situations, roles or task of members, cooperative methods, and service flows. The community has service types on the creation state and has members as available

services on the organization state. When some physical devices are not available, other devices in same types that can do the same function are recommended.

Organization is similar to instantiation process in the Object Oriented Model. Community manager searches available services which coincide with service types in the community template and admits the service to a member according to policies. After organizing, when new service or new device is discovered, the community may be reconstructed. This organizer can be implemented diverse methods.

Activation/Deactivation is related to achievement of permanent goal. If the permanent goal is fixing indoor temperature, members are not changed frequently. So, Activating/Deactivating community is more effect than organizing community whenever temperature gets out the critical temperature. We describe activation situation and goal situation in community template. When environment situation matches with activation situation, the state of community is activation while members in the community perform required actions. When environment situation matches with goal situation, the community is deactivated. However, higher priority community like emergency community can deactivate other activated community to manage resource even if the environment is not the deactivation situation.

Extermination is a process after achievement of temporal goal. When maintenance of community is not needed after achieving a goal, community is dissolved. Until activation situation becomes again, the community does not exist. The community execution is no more required, the community will be expired. The community no longer has references of community members.

3.4 Service List

Once the service is selected, the Community Manager invokes required service through service invocation method. In our smart home, we expose the service interface through soap protocol to service invocation components. Consequently, any

Table 2. The Service List of CUS Smart Home and Its Communication Protocols

Services	Functions	Communication Protocol
Light	On/Off Dimming Emotional Light	RS 232
Audio	*RCS	IR
TV	RCS	IR
Fan	RCS	IR
Air Cleaner	RCS	IR
Magic Mirror	Display Voice Recognition	IR
Heater/Stove Air Condition	Heating Cooling	IR
Curtain	Open/Close	RS 232
Door	Open/Close	RS 232

***RMC: Remote Control Service**

devices or components can implement our supported services. Basically, the automation system is provided with several communication protocols. Table 2 shows current the service list in our smart home as of May 2007 and controlling methods with communication protocols.

4 Intelligent Services for Ubiquitous Smart Home

We have described basic components that Ubiquitous Smart Home should have. In this section, we suggest three different service scenarios and its implementation through our system.

4.1 Replacing Malfunctioning Service

Problem. *The air condition runs while a residence is watching TV. However, the air breaks down and can't keep cooling temperature any more.*

Solution
Sensing Infrastructure. The system figures out that the user stays at Living room through deployed location sensors. When the user interacts with the mobile home pad to watch TV the signal is transferred to the Community Manager through context broker. With this process the system or community solution figures out the user's intention to watch TV and create TV Community.

Creation of Community. When the residence turns on the TV through mobile home pad, ***TV Community*** is created by Community Manager. As a result, the TV, emotional light and air join the community as community member and provide their own service to create best environment of TV watching.

Detecting Problem. The digital devices should reports their status periodically if they equip with the home network protocol. We assume any devices are equipped with the home network protocol and the community solution keeps receiving the "***Hello***' packet to figure out if the device works fine. When the air breaks down it can't send the ***Hello*** packet and the community solution understands one of the members doesn't work correctly.

Service Recovery and Intelligent Decision. When the Community Manager figures out the one of the member doesn't correctly it searches for alternative service through service discoverer which is described as meta-service. In this scenario, the service discoverer finds the fan in the living room and reports to the manager. After all, the manager makes the fan runs through service invocation. In our system, the web service is provided for communication methods between invoker and service provider which send control signal to final end devices.

4.2 Resolving Confliction of Services

Problem. *A wife is sleeping while a husband is watching TV. The wife can't sleep well because the TV sound and light from living room.*

Solution

Sensing Infrastructure. In the bed room where the wife sleeps at, environmental sensing infrastructure is deployed such as light and noise detection sensors. They keep reports current sensing information to the community solution system. Also, there is pressure sensor on bed and it detects the movement of wife while she stays.

Creation of Community. When a wife went to bed the system figures out that she trying to get sleep. The Community Manager creates ***Sleep Community*** and sets up the goal such as quiet and dark environment of bed room. Also, when the husband turns on the TV, the TV community is created by Community Manager. As a result, there are two communities in the house and the Community Manager tries to provide best services for both of them.

Detecting Problem. Because of the noise and light from living room the wife can't sleep well and she keeps moving on the bed. The different value pressure sensors are transferred to the system continuously and Community Manager understands that she can't fall asleep well.

Resolving Conflicts and Intelligent Decision. The Community Manager tries to find the reason of this situation through the sensing information. When the manager checks the noise and light sensing information of bed room it figures out the value of information exceeds the limitation of best sleeping environment. Now, the Manager looks for the source of noise and light all over the community currently created and finally finds that the TV sounds and lights of living room cause the problem. It is possible since the Community Manager manages and controls current status of devices in the house or all of the active communities. Since the Manager should provides best service for both of users it controls level of volume and lights little by little until both user are satisfied. So, the level of volume and light are decreased according to amount of movement of wife. We implemented following equation to achieve this situation and the level of them are strongly depends on the movement of wife.

$$\text{Movement} = (\{(n(A) - n(A')) / n(A) \} * 0.6) + \{(n(B) / (12 - n(A)) * 0.4)\} \quad (1)$$

In this equation, ***A*** represents the set of touched sensors at the first time, ***B*** represents the set of touched after moving, and ***A'*** represents the subset of A and touched after moving. With this equation we can find the amount of movement and the manager can control the lights of living room until she falls asleep.

4.3 Stress Index Based Service

Problem. *After work, when the residence comes back home the smart home makes best environment for him to decrease his stress according to current situation index.*

Solution. We developed the index based services which is called Wellbeing index based services. To achieve this goal, the system should always figures out about

user's information such as biometric, event, and environment information. With utilizing this information, the system defines current situation of user as numerical stress value and provides appropriated service to decrease the stress.

Sensing Infrastructure. In our wellbeing index based system, the smart home needs to understand user's information not only his or her profile but also diverse type of information. Mainly, current system considers three different type of information of each user. First of all, user's biometric information is required. Secondly, the environmental information around user is another critical factor and final information is user's event of current days such as promotion or wedding. For the biometric information we deploy the biometric watch and this device collects the user's biometric information such as blood pressure, heart rate, blood pressure, ECG, in-exhale, and body temperature as long as he wears the watch. Also, the environmental information of home is absolutely considered which are temperature, humidity, noise, CO2, and lights information. We can collect this information easily with our deployed sensing system. Finally, we have to consider the system should figures out the current event information but we can't detect this information automatically at this time. So we just assume the simulated event data.

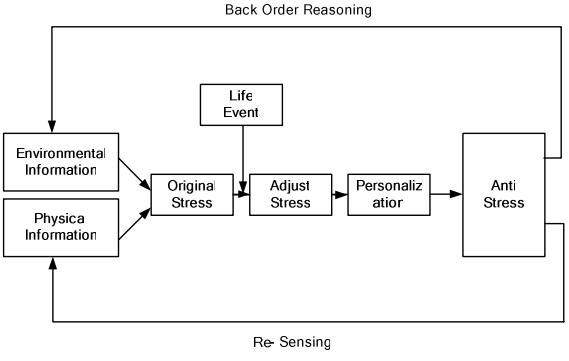

Fig. 7. Wellbeing Index Service Framework

Detecting Problem. Figure 7 shows the method or framework of defining current stress index. This framework utilizes environmental, biometric and life log of user to find the stress index and provides appropriate anti –stress service. This framework defines the original stress index with the found environmental and biometric sensing information as scale between one to three levels. The event score such as score of wedding, score of promotion, score of decease is considered to define the adjust index of stress. After define the final stress index the system personalizes this system based on the survey or feedback from user. As a result, the system always defines the user's current situation as numerical value and defines which service should provide.

Providing Anti-stress Services. After research on the anti-stress services we found the Music, Color, and Air service might help to decrease the stress. We apply this

result on our wellbeing system and following tables shows anti-stress services for each stress level. In this scenario, the system plays classical music, emotional light and spray lilac scent.

Table 3. Anti-Stress Service for each Stress Level

Stress Level	Music	Color	Air
0	Slavonic March, Romance, Carmen	Blue, Grey, White, Brown, Green	Peppermint, Lemon Lavender
1	Requiem, Ave Maria, Auferstehung Symponie	Green, Purple, Blue, Red	Peppermint, Lemon Lavender, Rosemary
2	Requiem, Nacht und Traume Wiegenlied	Green, Purple, Blue, Red	Peppermint, Lavender, Rosemary
3	Requiem, Ave Maria, Jardins sous la pluie La Symphonie pastorale	Green, Purple, Blue,	Peppermint, Lavender, Lemon

5 Conclusion

In this paper, we define three components to develop smart home for Ubiquitous era. The smart sensing infrastructure and rich type of sensing information provide basic background of smart home. Secondly, the intelligent decision maker is critical factors and brain of smart home and we suggest the community computing will play this role, final factor is the diverse service list that Ubiquitous smart home can provide. Our research is still working on these three components will create better smart home for near future.

Acknowledgments. This research is supported by the Ubiquitous Computing and Network (UCN) Project, the Ministry of Information and Communication (MIC) 21st Centry Frontier R&D Program in Korea.

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