The Ubiquitous Home

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Abstract Owing to the progress of wired and wireless home networking, sensor networks, networked appliances , mechanical and control engineering and computers themselves, we can realize smart homes nowadays and many smart home projects are proceeding in the world What we have to be careful is not to repeat the same thing as the h ome automation technologies that were booming in 1970's. That is to say, automation should not become a goal of the smart home technologies. In this paper, a real-life test bed, called the "Ubiquitous Home," is presented. In the Ubiquitous Home, a robot plays a role of interface for the residents. Three kinds of context-aware servi ces have been implemented and a real-life living experiment was conducted. The experimental results are reported.

Keyword: Smart home, interface robot, context-aware service, real-life living experiment

1. Introduction

We can trace home automation (HA) technologies in 1970's to one of the roots of smart home. It is no denying that these technologies cannot be said to have succeeded to improve our lifestyle so much except for infrared remote controllers of consumer appliances. There are several reasons. Firstly, one could not find economical merits for the HA technologies. Namely, the effects these technologies bring about were not so large in comparison with their costs to introduce and they did not contribute to energy saving of the house totally. Secondly, the system of HA technologies was so inflexible that one had to construct a new network infrastructure to be needed and the system was not able to change according to variation of the life style and the family members. Thirdly, the HA technologies were lacking the application or service from the viewpoint of users. What technologies can do differs from what users want. Although it is sometimes said to be a problem of killer applications, research and development from the users' standpoint are required.

Going into 1990's, so-called ubiquitous computing [1] or pervasive computing technologies have been realized owing to the progress of wired and wireless home networking, sensor networks, networked appliances, mechanical and control engineering and computers themselves. Using these developed technologies, smart home projects have started at every corner of the world. The project has its own goal and it seems that some novel findings have been dug out. Upon this stage, however, we have to be careful not to repeat the same thing as the HA technologies as Intille advises "researchers and technologies are more cautious in predicting the future of the home" in [2].

Purpose of each smart home project is mainly targeted at how to detect the residents' situation and their contextual information in a real life. Although this contextual information is able to use in order to realize context-aware services, the definition of context differs from each project or researcher.

In this paper, a basic definition of context is proposed and implementation of context-aware services in a real-life test bed is presented. Also, 16 days experimental results with a couple of husband and wife in this test bed are reported.

This paper is organized as follows. The related works are reviewed in Section 2 and Section 3 describes the smart home built in our project in detail. In Section 4, after main contextual information is defined, three kinds of context-aware services are described. Finally the real-life experimental results are shown in Section 5.

2. Related Works

The real-life living space test beds are sometimes called a smart home or sensor-embedded house, and several researches are reported. The works on the smart homes within about one decade ago from today are reviewed as far as possible

In 1995, the Welfare Techno Houses in Japan was constructed [3]. The concept of these experimental houses was to promote independence for elderly and disabled persons and to improve their quality of life.

The Aware Home [4] project is noteworthy among the smart home researches. In the Aware Home project, they built a three-story, 5040-square-foot home that functions as a living laboratory for interdisciplinary design, development and evaluation. The University of Texas at Arlington has conducted MavHome project [5]. The MavHome is a home environment that perceives the state of the home through sensors and intelligently acts upon the environment through controllers. Also, at the Massachusetts Institute of Technology, the House_n group [6] is working towards a vision where computer technology is ever-present, but in a more subtle way than often advocated in popular culture and even in engineering paper motivation sections. They want sensor-driven pervasive technologies to empower people with information that helps them make decisions, do not want to strip people of their sense of control over their environment.

Extended from Robotic Room 2 [7], Sensing Room was constructed at the University of Tokyo [8]. Although they say Sensing Room can measure detail of human daily behaviors in a long term, it seems that there is some limitation to imitate a real-life within a small room only.

The sensing room of EasyLiving project at Microsoft Research [9] is similar to Sensing Room. In EasyLiving project, they aimed at developing prototype architecture and technologies for building intelligent environments.

The University of Florida's Mobile and Pervasive Computing Laboratory is developing programmable pervasive spaces in which a smart space exists as both a runtime environment and a software library [10]. The University of Sherbrooke of Canada constructed DOMUS laboratory, which is a new research pole on cognitive assistance in smarts homes and mobile computing [11]. As DOMUS laboratory is situated in the University of Sherbrooke, atmosphere is different from real-life in a sense.

Active Home is also located in a university, Information and Communications University of Korea and several experiments of context-aware services according to human behaviors are carried out [12]. UbiHome is another smart space in Korea, where automated control of lights and monitors according to user's situations are demonstrated, for example [13].

3. Ubiquitous Home

3.1 The outline of the Ubiquitous Home

We also constructed a real-life test bed, called the "ubiquitous home," for home context-aware service experiments [14]. It is an ICT housing test facility for the creation of useful new services for the home that will become possible by linking devices, sensors and appliances by means of a data networks.

The layout of the Ubiquitous Home is shown in Fig. 1. At the Ubiquitous Home, experimenters can collect real-life data as if living in their own house, not in a laboratory. The Ubiquitous Home differs from other test beds in three aspects: first, we have enhanced ubiquity of sensors in the Ubiquitous Home; that is, we have installed many cameras and microphones in each room and various types of sensors to monitor locations in every space of the home. Second, we have set up a remote Japanese-style room, with which we can test remote family connectivity and create a test bed for specific Japanese services. Third, we have introduced robots in home service (Fig. 2). The robot is called Phyno and has a camera, a microphone and a speaker. Its neck has three degrees of freedom (DOF), its arm does one DOF and its waist does one DOF. Using the camera, Phyno can recognize registered user faces. A decomposed eigenface method is used for the face recognition. The method realizes robust recognition under various lighting conditions.

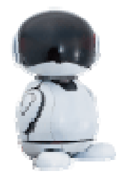

Fig. 2. The robot in the Ubiquitous Home.

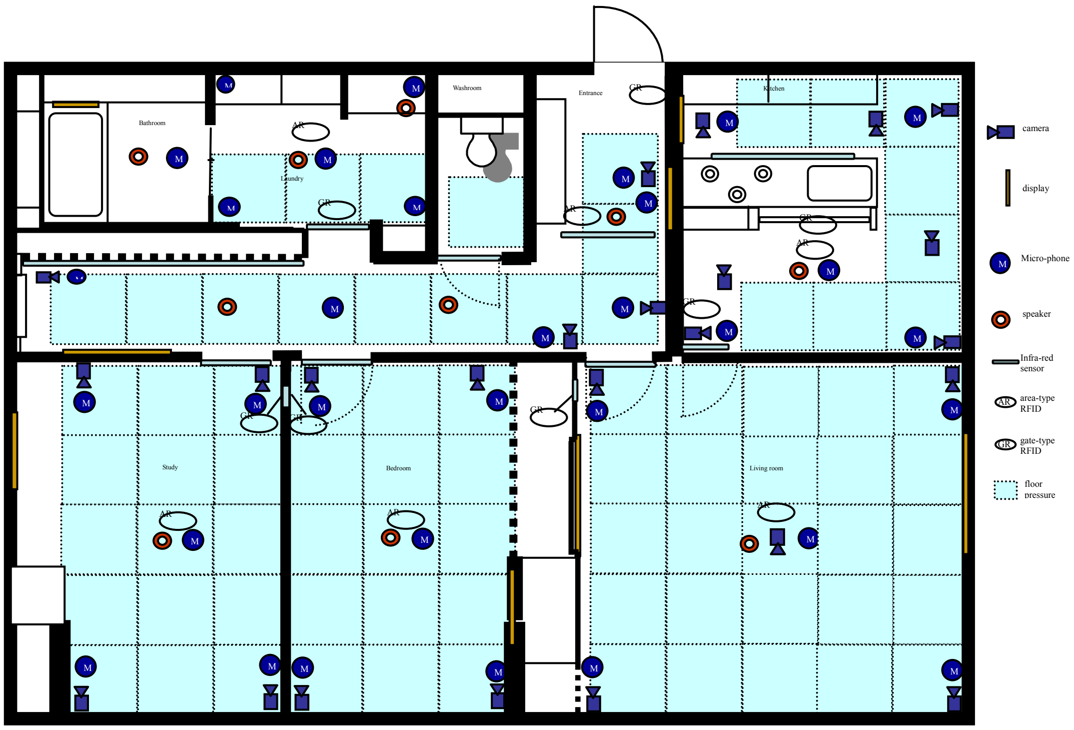

Fig. 1. The layout of the Ubiquitous Home.

The Ubiquitous Home has a living room, dining-kitchen, study, bedroom, washroom and bathroom, these rooms comprising an apartment. In addition to the apartment, a Japanese-style room is provided as a living space for remotely living family members, such as a grandmother and/or a grandfather. Between the apartment and the Japanese-style room is a computer room called the Network Operating Center (NOC).

Above the ceiling of the Ubiquitous Home is a space where experimenters can work. In the space, three corridors called "cat walks" are established. These are used for walking, machine installation and cabling, respectively. Moreover, the floor of the Ubiquitous Home is structured for free access to 40 cm height.

Fig. 3. Camera and microphone in ceiling.

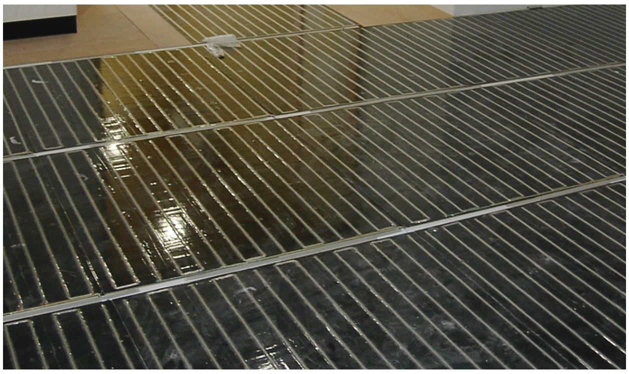

Fig. 4. Floor pressure sensor.

Fig. 5. Infra-red sensor.

Fig. 6. Plasma display on the wall.

The Ubiquitous Home is equipped with various types of sensors to monitor living human activities. Each room has cameras and microphones (Fig. 3) in the ceiling to gather video and audio information. To respect residential privacy in such ubiquitous camera and microphone environments is one of the important issues to be considered.

Floor pressure sensors (Fig. 4) installed throughout the flooring contain 18 cm by 18 cm binary detection units and are used to track residents or detect furniture positions.

Infra-red sensors (Fig. 5) installed at the top of the entrance door to each room and at foot positions in the kitchen and in the corridor detect infra-red sources literally, so can be used to detect human movement.

Two RFID systems are installed in the Ubiquitous Home. One is an active-type RFID system, the other is a passive-type RFID system. The former uses 315MHz waves, the latter the 2.45 GHz band. Active-type system scanners located over the ceiling of each room detect the entrance of RFID tags into the room. Passive-type system antennas are embedded inside the wall around each room entrance. When an RFID tag passes through the entrance, the antenna reads the information on the tag.

Four accelerometers or vibration sensors are attached to back of the bedroom floor in four corners. Although the role of the accelerometers is similar to the floor pressure sensors, they are more promising to detect human behaviors owing to their higher precision than the floor pressure sensors.

Displays (plasma display panels and liquid crystal displays) (Fig. 6) and speakers are installed throughout the Ubiquitous Home to provide residents with video and audio contents.

As described in the above, the Ubiquitous Home is a highly networked and sensor-embedded home and considered as the unconscious-type robot which is invisible to users and autonomously controls appliances on the network in accordance with various kinds of sensor information. On the other hand, the robot shown in Fig. 2 that actually exists and a resident recognizes as it is at a glance is needed to intermediate between the unconscious-type robot and the resident. This is the visible-type robot and the human-machine interface in the Ubiquitous Home.

4. The context-aware services implemented in the Ubiquitous Home

To provide a service to (a) user(s), contextual information, that is user context, should be considered. Although the definition of user context may change according to the situation or the service used, who, where and when are usually main contextual information. In the Ubiquitous Home, personal identification can be obtained from the active-type RFID tag worn by the resident or the face recognition by the visible-type robot camera. The place information can also detected by the active-type RFID tag and the time information can be provided a computer clock which is adjusted by a Network Time Protocol (NTP) server.

With the above contextual information, context-aware services are implemented in the Ubiquitous Home.

(1) TV program recommendation service

When a resident orders the visible-type robot to turn on the television in the living room of the Ubiquitous Home, the visible-type robot turns on the television by using network commands and selects the TV programs that the resident is like to watch. The selection can be done by comparing the EPG (Electronic Program Guide) information and the TV watch history data of the resident. For example, if a word in one TV program EPG information appears in the history data, the TV program would be recommended.

(2) Cooking recipe showing service

When a resident utters a word of food, the visible-type robot selects a recipe related to the word. The resident can continue recipe search by talking with the visible-type robot repeatedly. Once the recipe which the resident wants to use, the recipe can be presented on the television in the living room or the kitchen the Ubiquitous Home.

(3) Forgotten-property check service

An RFID is attached to each property which a resident goes out of the Ubiquitous Home. In addition, the properties that the resident should bring with him/her are listed up for each destination to go out. When the resident goes out, he/she can check the properties to be brought at the entrance hall by using the RFID tag reader installed in the shoes box of the Ubiquitous Home. We have implemented a demonstration service in the Ubiquitous Home. It demonstrates collaboration of a refrigerator, a plasma display panel and the area-type RFID system. The refrigerator has an inside camera to capture an image of contents in the refrigerator. The demonstration service is that the image captured by the inside camera could be shown onto the closest display panel to the user.

5. Real-Life Experiment by Elderly People

We conducted a real-life experiment fro 16 days from January 14th to 29th, 2006. The subjects (residents) were a couple of husband and wife in their sixties. They are not researchers and called “the man” and “the woman” in this paper.

5.1 Qualitative Evaluation

The man and woman lived in the Ubiquitous Home for 16 days as if it is their own home. They used the context-aware services described in Section 4. The TV program recommendation service was well received on the whole because we collected their two weeks TV watching data before the experiment. The cooking recipe showing service was also used very often, about three times per day on the average. The woman pointed out that it would be better if the service was linked with the foods left in the refrigerator. For both of the TV program recommendation and cooking recipe showing services, a partial recommendation might not interest the user sometimes. Some randomness might be helpful to arouse the interest of the user. About the forgotten-property check service, there were tag-reading failures when the tags were layered or the tag was inside a wallet. There is a need to improve tag-reading accuracy.

5.2 Quantitative Evaluation

The man and the woman were asked to evaluate Phyno’s ability for dialogue and face recognition. Evaluation was 7 scores: 7 was the highest (best) evaluation and 1 was the lowest (worst) evaluation. The evaluation results are presented in Figs. 7 and 8.

For the days of 8 and 9, there were troubles for Phyno and it did not work. Therefore the evaluation for this period was the lowest. Except for this period, the average score for the dialogue ability is 3.71 for the man and 4.14 for the woman. The average score for the face recognition ability is 4.21 for the man and 4.71 for the woman. The evaluation by the woman is a little higher than that by the man because it is considered that the woman spent with Phyno more time and used the cooking recipe showing service more often.

Regarding comparison between dialogue and face recognition evaluation, the dialogue evaluation tends to increase slightly as the days proceed while the face recognition evaluation goes upward and downward day by day. It is considered that it is difficult for the user to decide the distance from Phyno for the face recognition.

6. Conclusions

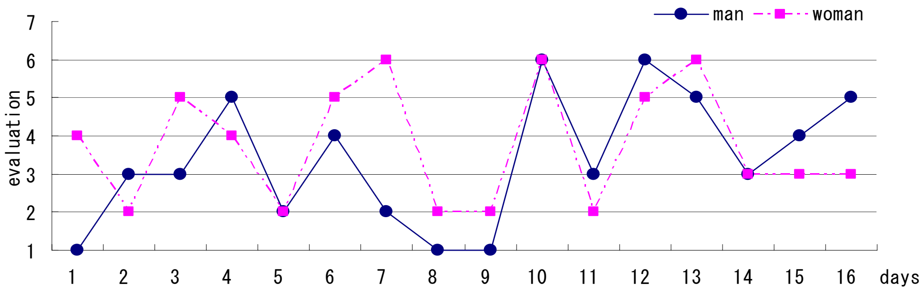

Fig. 7. Evaluation of Phyno's ability for dialogue.

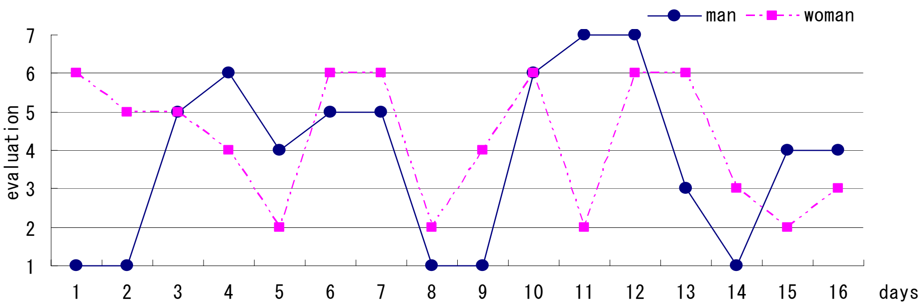

Fig. 8. Evaluation of Phyno's ability for face recognition.

In this paper, I addressed the issue that technologists and researchers in smart home research and development field should consider. The goal in this field must not be to construct automatic home environments. We must go beyond the smart home that carries out automated tasks instead of us.

As a real-life experimental smart home, we constructed the Ubiquitous Home where several context-aware services were implemented. Phyno is the dialogue-based interface robot and intermediates between the Ubiquitous Home and the resident. To evaluate the context-aware services and Phyno' s ability, we conducted a real-life experiment in which a couple in their sixties lived in the Ubiquitous Home for 16 days and some experimental results were presented in this paper.

Acknowledgment

The author would like to thank all contributors in the project related to the Ubiquitous Home for their support. The members of the project are Toshiba Corporation, NEC Corporation, Sanyo Electric Corporation, Oki Electric Industry Co., Ltd., Dai Nippon Printing Co., Ltd., Samsung Electronics Co., Ltd., Kyoto University, NARA INSTITUTE of SCIENCE and TECHNOLOGY, Doshisha University, Ritsumeikan University, Osaka Institute of Technology, University of Tokyo, Bukkyo University, Kochi Women's University, Wakayama University, Okayama University and National Institute of Information and Communications Technology.

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