International Conference on Control, Automation and Systems 2007
Oct. 17-20, 2007 in COEX, Seoul, Korea

Building a Smart Home Environment for Service Robots Based on RFID and Sensor Networks

Seung-Ho Baeg, Jae-Han Park, Jaehan Koh, Kyung-Wook Park, Moon-Hong Baeg
Control and Perception Research Group
Korea Institute of Industrial Technology (KITECH)
1271 Sa 1-dong, Sangrok-gu, Ansan, 427-791, South Korea (ROK)
(Tel : +82-31-400-3965; E-mail: {shbaeg, hans1024, jaehanko, kwpark, mhbaeg}@kitech.re.kr)

Abstract: This paper is concerned with constructing a prototype smart home environment which has been built in the research building of Korea Institute of Industrial Technology (KITECH) to demonstrate the practicability of a robot-assisted future home environment. Key functionalities that a home service robot must provide are localization, navigation, object recognition and object handling. A considerable amount of research has been conducted to make the service robot perform these operations with its own sensors, actuators and a knowledge database. With all heavy sensors, actuators and a database, the robot could have performed the given tasks in a limited environment or showed the limited capabilities in a natural environment. We initiated a smart home environment project for light-weight service robots to provide reliable services by interacting with the environment through the wireless sensor networks. This environment consists of the following three main components: smart objects with an radio frequency identification (RFID) tag and smart appliances with sensor network functionality; the home server that connects smart devices as well as maintains information for reliable services; and the service robots that perform tasks in collaboration with the environment. In this paper, we introduce various types of smart devices which are developed for assisting the robot by providing sensing and actuation, and present our approach on the integration of these devices to construct the smart home environment. Finally, we discuss the future directions of our project.

Keywords: Smart Environment, Service Robotics, RFID tags, Sensor Networks

1. INTRODUCTION

A smart environment is a physical world that is interconnected through a continuous network abundantly and invisibly with sensors, actuators and computational units, embedded seamlessly in the everyday objects of our lives [1].

A smart home is a residence in which computing and information technology apply to expect and respond to the occupants' needs and can be used to enhance the everyday life at home. Potential applications for smart homes can be found in these categories: welfare, entertainment, environment, safety, communication, and appliances [2].

This environment as a ubiquitous computing concept becomes reality after Mark Weiser introduced this new computing paradigm [3]. Smart devices which are principal components of a smart environment are made up of sensors, actuators, and communication modules that seamlessly interconnect them. Besides, there is a server that manages and operates the overall components of the smart environment. Thus, the core technologies for studying smart environment include: (i) technologies of sensors and actuators that interact with the real environment; (ii) communications technologies which connects devices with the environment; (iii) management technologies that collect and manage data from the devices and make decisions based on the data [1].

One of the major challenges to make the robot industry to grow is that we need to develop flexible and autonomous robots with low-cost hardware. However, because of the cost constraint, most robotic products provide very limited autonomous functionality [4].

Much of research on classical robotic platform has focused on perceiving its environment and storing data onto its database for future use. In this approach, the robot is equipped with many expensive sensors and it works based on some complex algorithms and a huge database for decision-making. However, despite this heavy configuration, the performance of the robotic system was not very satisfactory. However, in our smart environment for service robots, a light-weight robot can perform complex tasks and provide reliable services in which the environment is full of RFID-tagged objects, sensors, actuators, service robots interwoven through wireless communications networks. The robot in our smart environment can not only utilize data about the status of the environment from distributed smart devices but also control the devices through smart actuators connected to the home server. The prototype smart home environment has constructed in our research building in Ansan, the Republic of Korea (South Korea). Suppose the robot needs to turn on a light in the smart home for some reason. In the classical robot settings, the robot should calculate the position of the light switch in space through vision processing and object recognition while moving towards the light switch, and then move its arm to touch the switch. In our robot-in-the-smart-environment settings, the robot does

978-89-950038-6-2-98560/07/$15 ⓒICROS

not need to be outfitted with cameras for recognizing the switch, nor arms for turning on the switch. All it needs is just the network address of the switch. Like this example, in our settings, the price of the robotic system can go down while ensuring the recognition accuracy. Another advantage of our environment is that a symbiosis between the robot and the environment makes it possible to perform any complex tasks. Thus, the low-cost robot with a camera, an RFID reader and a communication module can perform many sophisticated tasks while ensuring reliability. We expect this can pave a path for service robots to enter into our daily lives and to liberate us from daily chores.

Our paper is organized as follows. Section 2 introduces the RFID technology and our version of the smart environment. In Section 3, we describe the physical architecture of our smart home environment along with smart devices developed so far. Section 4 concludes our work and presents the future direction of our research.

2. SMART HOME ENVIRONMENT FOR SERVICE ROBOTS

2.1 RFID Technology into Our Smart Environment

RFID is a means of identifying a person, an animal or object using a radio frequency. An RFID tag consists of a semi-conductor chip and an antenna that can transmit data to a wireless receiver. The RFID tag reader communicates with an RFID tag and powers the tag when the tag is a passive one that has no battery. The RFID reader of the mobile robot handles the communication between the RFID tag and the central processing unit (CPU) of the robot itself. RFID technology has been introduced to be used in applications such as delivering packages, handling luggage, collecting toll. Major retailers such as *Wal-Mart, Target* and *Home Depot* have already invested a lot in this technology to enhance efficiency and to track shipment of their products [5].

Taking into consideration that the tag cost is continually going down and the commercial usage of the tags is near, we installed RFID-tagged objects in our home environment.

2.2 Conceptual Description of the Smart Home Environment

A smart environment is a physical world where smart items, sensors and actuators are placed and they are invisibly and seamlessly interwoven through a continuous network [1].

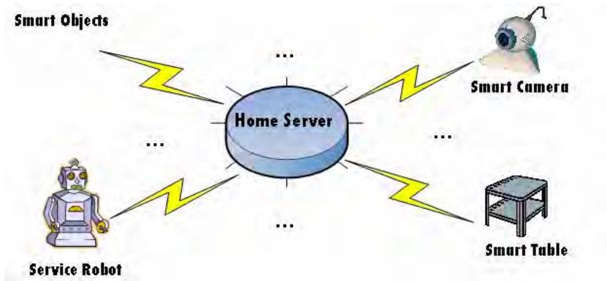


Fig. 1 Conceptual architecture of our smart environment.

Fig. 1 shows the conceptual architecture of our smart environment. Our system mainly consists of three components: *smart objects* including smart tables, smart cameras; *the home server* managing data and maintaining connectivity among smart objects; and *a service robot* conducting housekeeping tasks.

Basic elements of our environment are smart items. *Smart items* are RFID-tagged items or objects. They have an RFID tag attached to it and only are perceived either by smart objects or smart appliances. *Smart objects* are objects with either sensor capabilities or actuator capabilities or both. Since they have their own CPUs and an antenna, they can communicate with the home server through wireless networks. *Smart appliances* are electrical equipment or products having their own CPUs and communication modules. They can have either sensor capabilities or actuator capabilities or both. Since smart appliances and smart objects have RFID readers attached, they can perceive whether smart items are within their sensing range. We refer to smart objects and smart appliances as *smart devices* [6].

The *home server* manages smart items and smart devices, collects data about networked smart devices, makes decisions based on the colleted data, and controls the smart devices.

The *service robot* manages and controls the smart objects as well as provides reliable services by symbiotic interactions with the environment through the wireless communication networks. For our environment we employ a mobile robotics platform, *SmaRob-I*, equipped with a stereo vision camera, an RFID reader, and a wireless communication module.

Conceptually, our smart environment is divided into five levels as shown in Fig. 2: Level one refers to the real environment where smart items are scattered around. Level two consists of sensors and actuators. RFID readers, luminance sensors, temperature sensors, humidity sensors, smart security sensors and smart lamps fall into this level. Level three corresponds to smart devices such as smart tables, and smart shelves. Level four takes care of communication between smart devices and the home server. Level five indicates the smart home server which manages and operates the smart items and devices.

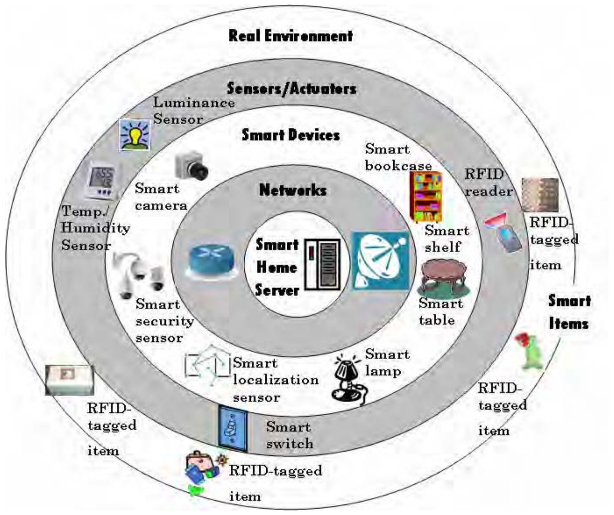


Fig. 2 Layered description of our smart environment.

2.3 Robotic System in Our Smart Environment

Generally, service robots for a home environment should have the following key functionalities: localization, navigation, map building, human-robot interaction, object recognition and object handling. To execute the functions, a classical robotic platform should be equipped with sensors such as a ultra-violet sensor, an ultrasound sensor, a razor sensor, a range finder, or a camera as well as with a computing system that has a big memory.

However, due to the advancements of sensor technology and integration, wireless communications, and wireless modules, most sensing equipment that was previously mounted on a robot can be installed in a surrounding environment. These changes allow a lightweight robotics system since the heavy workload to perceive and act in real-time can be distributed into the environment. Fig. 3 compares the classical robotic system that is a single monolithic one with our robotic system that is a lightweight one.

2.4 Services in the Smart Environment

We select three target scenarios for experiments that provide residents with reliable services in our smart environment considering current technological progress.

(1) **Cleaning up objects scenario**: This scenario starts with cleaning up an untidy living room in the morning by a service robot after the master goes to work. The robot should identify objects to arrange, put them in order and traverse the room with the help of a position recognition sensor installed on the ceiling of the room. It navigates within the room and identifies the requested objects by using RFID signals, pick up, carry and put the object down on the designated position. This scenario aims to intelligently execute given tasks such as putting clothes in a laundry bag, putting mugs in the sink, etc.

(2) **Executing errands scenario**: This scenario intends to identify and fetch a requested object. Since a target object is a smart item with an RFID tag, the smart devices such as a smart table, a smart shelf, and a smart bookcase can detect the presence of requested items around them. Once detected the RIFD code of the smart item is transferred to the home server through wireless networks. If the master issues a command "Fetch me my cup," the robot sends a request for the position of the cup to the home server. The home server searches for the status information of the device and then sends the position data to the robot. After downloading the data from the home server, the robot moves to the place where the target object is laid, grasps, brings it to the master.

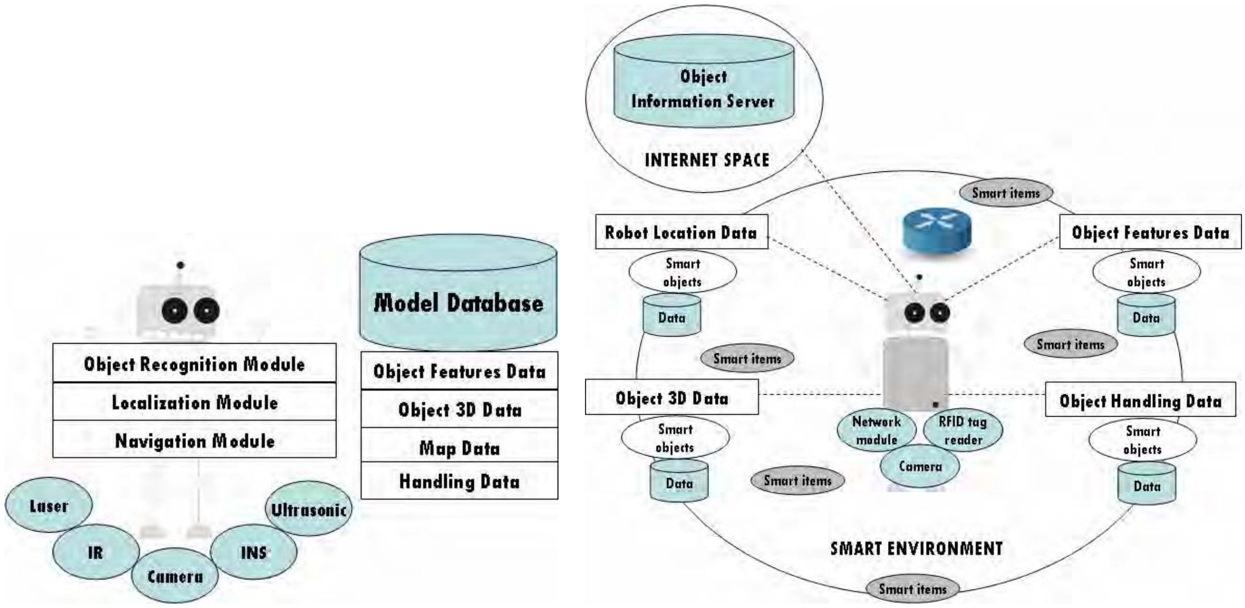


Fig. 3 (a) Classical Robotic System (b) Robot System in Our Environment

(3) **Security service scenario**: This scenario deals with intelligent services carried out by a communication between smart devices. When an intruder is detected by a smart security sensor, this event is immediately reported to the home server. The home server makes the robot move to a position where the sensor detects the intruder. After the robot moves to the sensor it turns on the smart lamp and video-capture the scene. If the intruder is detected, the recorded clips are transmitted according to the master's request.

3. CONSTRUCTION OF OUR SMART ENVIRONMENT

3.1 Key Modules of Smart Devices

For the implementation of the scenarios mentioned earlier, we need to pay attention to two key modules: *communication modules* and *RFID interface modules*.

Communication modules operate using the ZigBee protocol. The ZigBee protocol is an open standard on the basis of 802.15.4b providing low-power, wireless connectivity for a wide range of applications. This protocol is adopted for all our smart devices. For RFID modules we employed EPCglobal Gen2. EPCglobal Gen2 was initially developed by world's leading technology companies aiming at creating standard interfaces and protocols in the development of new RFID hardware products. Because of its global acceptance and popularity, we chose the standard and developed RFID interface modules in accordance with it.

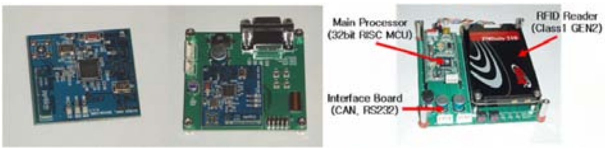


Fig 4 Key modules of smart devices.
(a) ZigBee communication module (Left)
(b) RFID interface module (Right)

3.2 Implementation and Installation of Smart Devices

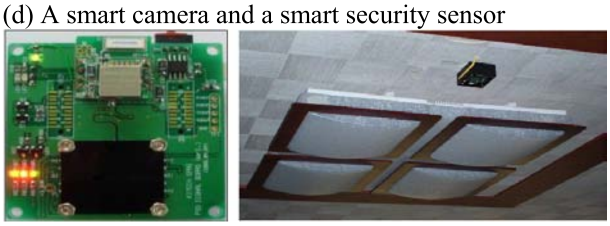
Many smart devices were developed based on the key modules introduced in the previous section. Fig. 5 shows the smart devices. Fig. 5(a) shows a smart table having two RFID modules and an antenna. A 32-bit ARM-based processor detects the status of smart items with their RFID codes and reports to the home server as events through the ZigBee communication modules. Fig 5(b) shows a smart shelf. Like the smart table, each shelf has two RFID interface modules and an antenna so they can detect smart items on them and can communicate with the home server. Fig. 5(c) shows a smart lamp. It provides a light control capability by turning on and off a relay, one type of actuators. Fig. 5(d) shows a smart camera and a smart security sensor. These are used to detect intruders and report the status to the home server. Fig. (e) is a smart localization sensor and this is very crucial for real-time autonomous navigation.

(a) A smart table

(b) A smart shelf

(c) A smart lamp

(d) A smart camera and a smart security sensor



(e) A smart localization sensor
Fig. 5 Various smart devices developed

The smart devices shown in Fig. 5 are installed as shown in Fig. 6. The prototype home environment has been built within the model house of Gyeonggi Technopark, Ansan, South Korea. This mimics the real-world house and aims to be used as a test-bed for future smart environment experiments. We plan to test the practicality of smart environment technologies and the effectiveness of robot services through this environment.

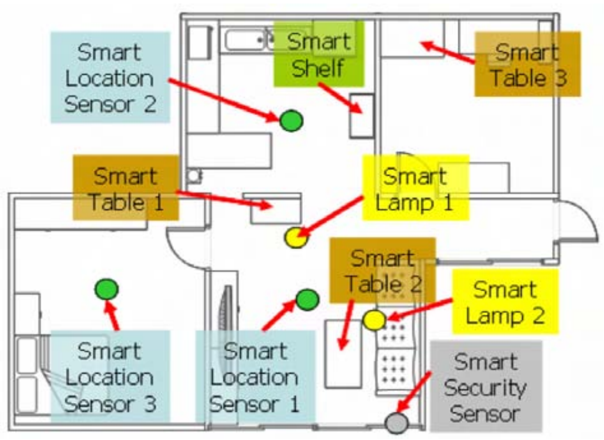


Fig. 6 The physical layout of the prototype home environment in our model house.

3. CONCLUSIONS AND FUTURE WORK

In this paper we describe the architecture and implementation of a smart environment with RFID-tagged objects, in which the home server acts as an intelligent collaborator between our mobile service robot and the environment. To demonstrate the practicability of a robot-assisted future home environment, we chose three scenarios, came up with devices required to provide reliable services, developed them, and implemented software for management and control. Smart items and smart devices were developed and installed in our prototype home environment.

The focus of our research project lies in helping human beings, not intelligent robots. Even though the robots utilize the smart environment, the robots themselves are merely agents that provide humans with services.

The goal of our project is to show the usability of the service robots in our daily lives by constructing the smart environment for the service robots. This attempt is expected to enable humans to focus on the important tasks by liberating ourselves from unpleasant daily chores with the help of services robots.

We plan to perform the floor cleaning task within our prototype smart home environment.

REFERENCES

[1] D. J. Cook and S.K. Das, "Smart Environments: Technology, Protocols, and Applications," *Wiley Inter-Science*, 2005.

[2] Frances K. Aldrich, "Smart Homes: Past, Presen t and Future," *Inside the Smart Home*, pp. 17-39 , London: Springer-Verlag UK, 2003.

[3] Mark Weiser, "The Computer for the 21st Cent ury," *Scientific American*, vol. 256, no. 3, pp. 66 -75, 1991.

[4] Niklas Karlsson et al., "Core Technologies for S ervice Robotics," *International Conference on I ntelligent Robots and Systems (IROS) 2004*, 200 4.

[5] Roy Want, "An Introduction to RFID Technolog y," *Pervasive Computing*, 2006.

[6] Seung-Ho Baeg, et al., "RoboMaidHome: A Sensor Network-based Smart Home Environment for Service Robots," *16th IEEE International Symposium on Robot & Human Interactive Communication (RO-MAN 2007)*, August 2007..