Architectures of an Extensible Home Automation System Based on Instant Messaging*

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〈Abstract〉

This paper is about the architectures of an extensible and scalable home automation system which is based on instant messaging. The extensibility is the most important feature of the system because there are very diverse appliances at home and they can be added or replaced with other products frequently. For the extensibility, we propose façade architecture for communication, distributed agent architecture for the system, layered architecture for agents, and bridge architecture for wrapping existing facilities. Using these architectures, we reduce the system complexity and get the extensibility to add new products with least cost. Furthermore, we also introduce our prototype system and show that it is extensible.

Key Words : Home Automation, Extensibility, Architecture, Façade, Agent

Ⅰ. Introduction

Home automation systems will be very popular in the near future because home appliances have been having computing power, and some of them have been connected to the Internet. Furthermore, the number of appliances at home have increased. In average American home, the number of electronic appliances has increased from 1.3 in 1975 to 25 in 2006 [1]. Based on this situation, there have been lots of researches on home automation systems. We classify the services of them into four types: controlling, healthcare, safety and security, and entertainment.

Most of researches on home automation have focused on the communication protocol, middleware, and system implementation. They have paid little attention on the extensibility of home automation systems. In home automation, the extensibility is most important because users buy new kind of appliances and replace old appliances with new ones with different brands. Therefore, the home automation

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system should be able to support new appliances without redeveloping or rebuilding the system. It means that home automation systems require system extensibility. And this extensibility has close relationship with two non-functional system requirements: costs and usability. Adding new appliances or replacing appliances should require zero costs or the least costs from users. If the home automation system requires high costs whenever buying new appliances, users would not want to use the system. From the perspective of usability, the system should be easy to use and easy to add new appliances because users are very diverse: kids, adults, and the aged.

In order to solve the problems mentioned above, we propose an instant messaging based home automation system. The system follows façade architecture for communication, distributed agent architecture for the system, layered architecture for agents, and bridge architecture for existing facilities. For unified communication, we adopt instant messaging mechanism as the communication façade, so that any appliance can communicate with any other appliances through messaging. Instant messaging is good for home automation because it is real-time, interactive, message driven, and extensible. At system level, the system follows the distributed agent architecture. Agent means software module that represents an electronic appliance or a human being. Using distributed agents, users can add more agents for new appliances without redeveloping or rebuilding the system. Each agent follows the layered architecture to reduce complexity and to increase modularity. In the agent, there are communication layer, interpreter layer, and appliance specific layer. Each agent is connected to its corresponding appliance through a network, and there are a bunch of network standards. We adopt the bridge architecture to connect to these standard networks. For message format, we adopt XML format and the concept of vocabulary for each appliance. The vocabulary is related to the service or capability of each appliance. There should be interpreter or translator modules to communicate each other.

For verification of our proposal, we introduce our prototype system, named JCTalk [2]. It is based on our previous work [3], and it is being developed. It adopts open source instant messaging server, IR modules, power line communication (PLC) modem, and XMPP message protocol. It can control TV set and air conditioner using IR modules, and control a coffee maker using power controller. It also monitors temperature, humidity, and intensity of light. It is extensible enough to add new agents without redeveloping or rebuilding the system.

In this paper, we contribute four folds. First, the facade architecture for communication is helpful to reduce complexity and to increase extensibility. Second, distributed agent architecture is suitable for home automation system because it allows users to add new appliances without redeveloping or rebuilding the existing system. Third, the bridge architecture helps reusing the existing facilities and reducing costs and complexity. Fourth, we introduce a XML schema that allows appliances to communicate each other.

The remainder of the paper is organized as follows. In Section 2, we discuss other works that are closely related to our work. Then we introduce the concept of communication façade and some issues related to smart home system in Section 3. In Section 4, we introduce the cooperation model of agents. After that, in Section

5 we introduce prototype system JCTalk v.2. Finally, we reveal the conclusions of our work in Section 6.

Ⅱ. Related Works

We classify related work into two categories: middleware for home automation, and instant messaging used for home automation. The first group researches are Jini [4], UPnP [5], and HAVi [6]. These researches focus on developing middleware for low level communication in smart home. However, our main focus is how we can utilize smart home services on the top of these middlewares or other technologies.

The researches belonged to the second group are Arjun [7], Aurell [8], Rodríguez [9-11], and Cian Foley [12]. These researches use instant messaging to communicate with devices. In these researches, instant messaging is used as terminal for controlling and monitoring devices remotely. Rodríguez [9-11] adds context-awareness feature to the instant messaging and Cian Foley [12] extends the communication participants to human beings, devices, and even services. Compared to these systems, our main focus is the architecture of instant messaging based home automation which can monitor and control appliances at home.

Ⅲ. Architectures for Extensible Home Automation Systems

3.1 Requirements of Home Automation Systems

The functional requirements of home automation are related to the service types which the systems provide. We classify the services of them into four types: controlling, healthcare, safety and security, and entertainment. For controlling service, the home automation system should be able to mange power and mange appliance's facilities. For example, users should be able to change channel and volume through the system. For healthcare services, it should be able to monitor users' health status such as heart beat rate and blood pressure. For safety and security services, it should be able to detect any dangerous things including gas, fire, and thieves. For entertainment, it should be able to provide video and audio services and game services.

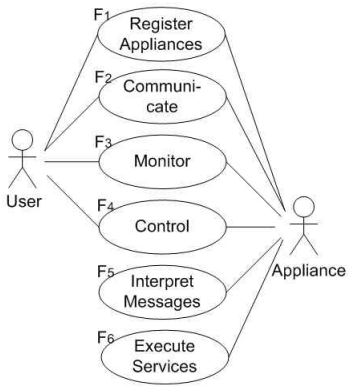
There are too many kinds of appliances to describe every function of all appliances. Therefore, we need to category the functions of home automation services into three: monitor, control, and communicate. We call these functions as generic functions. <Table 1> shows the generic functions and home automation services.

<Table 1> Service Types and Generic Functions

Service Types	Generic Functions	Service Examples
Controlling	Control	Turn on/off TV
Healthcare	Monitor, Communicate	Check heart beats
Safety/Security	Monitor, Control	Monitor door
Entertainment	Communicate, Control	Play Games

Using generic functions, we can concentrate main functional requirements. We can get six functional requirements for home automation systems. <Fig. 1> shows the use case diagram for generic functional requirements. Both users and appliances can register appliances to the home automation system. After registration, they can communicate through the

network to monitor and/or control appliances. The appliances should be able to understand the communication messages and to perform their services after the requests in the messages.

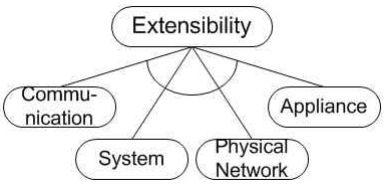


<Fig. 1> Use Case Diagram of Home Automation Systems

Aside the functional requirements mentioned above, the nonfunctional requirements are also very important in this system. We expect that the nonfunctional requirements determine the system architecture. From the features of home automation systems, we elicit the following nonfunctional requirements.

- (N1) Real-time Communication: The home automation systems should be able to support real-time communication because the services of monitoring and controlling are inherently real-time.
- (N2) Bidirectional Communication: In the home automation systems, both appliances and users should be able to be proactive and reactive. For example, to control appliances, users are proactive and appliances are reactive. On the other side, to notify events, appliances are proactive and users are reactive. Therefore, the communication should be bi-directional.
- (N3) Extensible / Expansible: The appliances in home automation are very diverse because there are a myriad of appliance products in the market. Appliance companies should be able to produce appliances and software systems in accordance with the standards with less cost and efforts.
- (N4) Easy to Configure: The systems should be easy to configure after users preferences. There is wide range of user spectrum, from kids to the aged, so that the configuration of the systems should be easy to set up.
- (N5) Low cost: Costs for home automation systems and smart appliances are one of the biggest obstacles, so that stakeholders should consider the cost problems. Because the cost for new appliances is the big portion of the costs, the system should support old fashioned appliances.

The functional/nonfunctional requirements determine the system architecture. In order for a home automation system to be extensible, it should be extensible in its communication, system, network, and appliance. <Fig. 2> shows the AND-OR graph for the extensibility requirements. To solve this issue, we consider the combination of multiple architectures: façade for communication, distributed agent for system, bridge for physical network, and extensible message format for appliances.



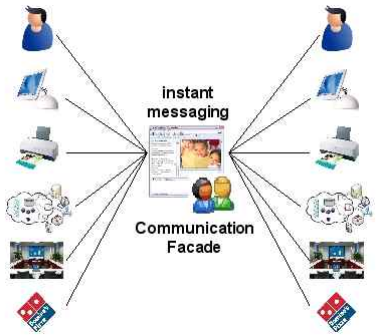
<Fig. 2> AND-OR Graph for Extensibility Requirement

3.2 Communication Façade Architecture

Home automation systems are heterogeneous systems. They support diverse appliances and networks including Ethernet, IEEE 1394, infrared, PLC, and other networks. These heterogeneous systems cause the complexity to support cooperation among appliances and to monitor and control the appliances. In order to solve this problem, the systems should be simple enough to reduce complexity, costs, and efforts.

In order to simplify home automation systems, we propose the communication façade architecture. It means that the systems should use unified network protocol for the services. As the unified network protocol, we choose the instant messaging protocol even though most of existing systems have adopted the web. The web is not suitable for some of nonfunctional requirements: N1 and N2. However, using instant messaging, even appliances can communicate with other appliances and/or human beings as do human beings in the traditional instant messaging. To treat appliances as the same as the human beings in the instant messaging, we call both human beings and appliances connected to the instant messaging as the communication entities.

By adopting instant messaging, it plays the role of communication facade. <Fig. 3> shows that the communication through instant messaging among appliances and human beings. Communication façade has three merits. First, it reduces complexity by eliminating the huge number of communication paths among appliances. Second, it mitigates the efforts to develop software modules to communicate with other appliances. Third, it reduces development costs by standardizing the communication model and APIs.



<Fig. 3> Communication Façade Architecture

Communication façade architecture is suitable for instant messaging based home automation systems. It meets all functional and nonfunctional requirements. In particular, it supports the extensibility by providing the unified communication among appliances and humans.

3.3 Distributed Agent Architecture

Distributed agent architecture is software architecture that consists of distributed and autonomous software module, named agents. It is suitable for complex systems in which interaction among participants occurs frequently for common goals. In this work, we define an agent as "a software module or a hybrid module of hardware and software that is autonomous, cooperative, and goal-oriented."

Distributed agent architecture has many merits: reducing complexity, providing intelligence, and providing extensibility. We adopt distributed agent architecture to get extensibility merits for home automation systems. Home automation system consists of multiple agents that represent appliances. Home automation system (HAS) is defined as a tuple of three components: Agents, Communication Means, and Services.

Definition 1: Home Automation System

HAS = (A, C, S), where

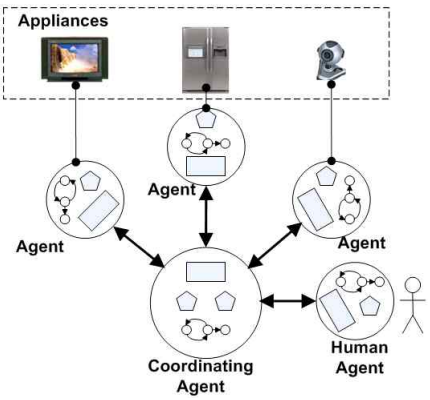
A = a set of software modules that represent appliances participated in the system

C = a set of communication means (communication media, protocol, message format, and vocabularies and their meaning)

S = a set of services which the system provides

The interesting features of an agent that we focus on are autonomy and loose coupling. First feature means that it has its own status, operations, policy, and some facilities to communicate and compute. Second feature means that it is independent to other parts, and it is replaceable with less cost.

<Fig. 4> shows the agent architecture for home automation system. It consists of agents each of which represents an appliance. And there is a central agent for coordination.



<Fig. 4> Distributed Agent Architecture

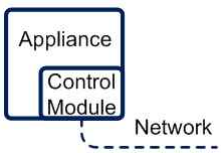
An agent represents an appliance, and they are connected each other through the network. In this work, agent is defined as Definition 2.

Definition 2: Agent

Agent = (T, O, S), where

T means the corresponding appliance, O means a set of operations which the agent provides, and S means the status of the agent.

An agent is connected to its corresponding appliance through network as shown in <Fig. 5>. The agent's operations are mapped into the operations of the appliance. The status of the agent represents the status of its corresponding appliance. The appliance should have a control module that is connected to the network.



<Fig. 5> Appliance and Network

Agents communicate each other to achieve goals, so that the communication means are required for agent systems. Communication means cover the whole things to communicate among agents. It is defined as follows.

Definition 3: Communication Means

C = (M, P, F, V), where

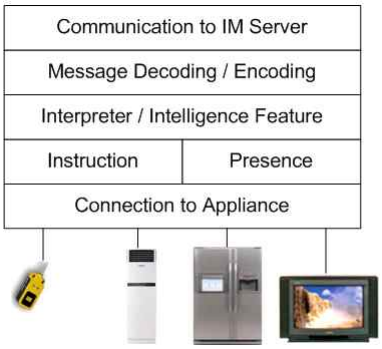
M means the communication media, P means the protocol, F means message format, and V means the vocabularies and their meaning.

Home automation services are the services provided by the home automation system. The services are provided by the cooperation or interaction of agents. Therefore, a service is defined as a sequence of interaction of agents.

Definition 4: Home Automation Services
S = (seq), where
Seq is a sequence of an interaction I: ak |→ al.

3.4 Layered Architecture

Home automation system follows the communication façade and distributed agent architecture. However, each agent follows the layered architecture to reduce complexity and to increase modularity. The agent has layered architecture as shown <Fig. 6>.



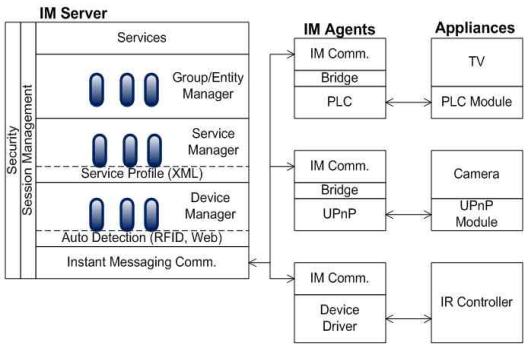
<Fig. 6> Agent Architecture

The lowest layer is "Connection to Appliance", of which role is to connect to the appliances through a network. The 2nd layer handles appliance specific instructions and presence information. The 3rd layer takes charges of smart operation. It infers the situation and makes smart instructions. The 4th layer decodes and encodes between appliance-neutral data format and appliance specific data or instructions. The 5th layers manage the communication to instant messaging servers.

3.5 Bridge Architecture

An instant messaging agent is the delegate of an appliance, or the bridge connecting the appliance and the instant messaging server. It involves the instant messaging communication module and the facility for connecting to its corresponding appliance. Some appliances are directly attached to the home server through LAN or serial/parallel cable, and others are connected indirectly.

<Fig. 7> shows the layout of instant messaging server and agents. In order to support middlewares with least costs, the agent adopts the software bridge that connects middlewares and the instant messaging communication protocol.



<Fig. 7> Bridge Architecture

Ⅳ. Agents Cooperation

4.1 Agent Cooperation Model

In home automation systems, the communication patterns among communication entities are classified into seven types according to communication entities,

dataflow among them, and the communication session. In the following categories, the arrows means the flow of messages, and the plus symbol means the communication session.

1. Appliance→User : Event Notification
2. Appliance→$^{+}$User : Monitoring
3. Appliance→User : Control
4. Appliance→$^{+}$User : Interaction
5. Appliance→Appliance : Control
6. Appliance→$^{+}$Appliance : Interaction
7. User→Appliance→$^{+}$Appliance : Smart Cooperation

The communication among agents should be done in accordance with purpose. According to our façade pattern, agents can communicate with any other agents. The message contents are binary data or text data. The binary data are connected to the external application. And the text data are processed by the instant messaging agents or interpreters.

The binary data should be interpreted according to the receivers' capabilities or the receivers' purpose. For example, temperature data sent to a printer agent will be printed by the corresponding printer. However, the same data sent to the air-conditioner will trigger its operation. Therefore, the data sent to a receiver are interpreted by the receiver, so that we call this as purpose oriented communication.

A service purpose determines message contents, the message source, and the message target. Therefore, if we elicit service list, we can determine the communication paths for the services.

For extensibility, the message source and the message target are replaced with other sources and other targets if they guarantee the compatibility of message contents. This extensibility allows users to replace old appliances with new appliances. For example, LG TV can be replaced with Samsung TV if they guarantee the compatibility of the message contents.

4.2 Communication Message Format

One of the most popular protocols for instant messaging is XMPP, which is open standard for instant messaging and there are lots of servers, clients, and libraries for this protocol. XMPP is based on XML, and it is extensible through XMPP Enhance Proposals (XEP) program [13], and about 200 XEPs have been proposed.

We propose our XEP for home automation. The communication protocol and message format are related to the communication language in agent fields. There have been many agent languages for agent communication including KQML.

Our proposal XEP should reflect the communication patterns and features of home automation. The communication patterns are explained in 4.1 section. The most important feature of home automation is the diversity. There are many kinds of appliances, and there are also many products for one kind appliance. Therefore, we have to consider commonality and variability to support properly home automation.

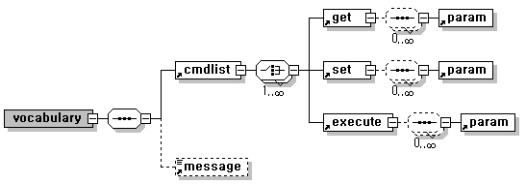
The home appliances can be classified into several groups. Appliances in a group have common features, and these common features drive common vocabularies according to groups. We classify the home appliances into 5 groups. <Table 2> shows the categories and example appliances.

<Table 2> Appliance Classification for Message Format

Category	Features	Example
TV	Multiple menu	TV
Player	Player (Play, Fwd/Rev, Skip)	Audio/MP3/ Video Player/DVD Player
Temperature	Serial menu	Refrigerator/Air-conditioner/Boiler
Time	Time	Oven, Range
Simple	On / Off	Light, Lock

In real home, we have different TV sets, and they provide different facilities. Therefore, we must have facilities to support different features according to different appliances. The message format should be able to support variability.

<Fig. 8> shows the XMLSchema for the message format [14]. The "cmdlist" element has multiple child elements: get, set, and execute. These elements represent commands of things, and each of them has "name" attribute for its command name. Furthermore, each command has multiple "param" elements for additional information, and it has "type" attribute for representing parameter type. The "message" element is for the initial message for communication such as welcome message.

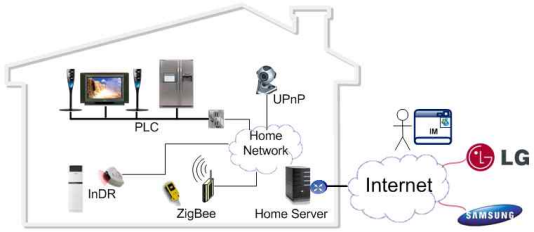


<Fig. 8> Vocabulary Schema

V. Prototype System

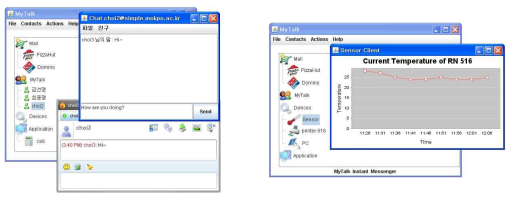
We are developing our prototype system, JCTalk v.2, based on our previous system, MyTalk [3]. We adopt Jabber and XMPP protocol, and use open source jabber server named openfire. We use Java language, especially with JDK 1.6 on Win 32 platform, and wireless sensor mote kit and infrared module from HyBus [15].

<Fig. 9> shows the components of the system. It adopts wireless sensor network for monitoring environmental condition: temperature, light, and humidity. In addition, it uses infrared signal to control appliances. The infrared has some shortcomings, but many appliances support infrared control.



<Fig. 9> JCTalk v.2 Architecture

<Fig. 10> shows the running examples of JCTalk. <Fig. 10> (a) shows the talking among human beings, and (b) shows sensor monitoring through instant messenger.



(a) Talk (b) Sensor Monitoring

<Fig. 10> Running Examples

VI. Conclusions

In the home automation systems, the extensibility is very important because appliances are added and old ones are replaced with new ones. Furthermore, the systems should support extensibility with no additional costs or with the least costs for their success in the market.

In this paper, we proposed the communication façade architecture for communication among communication entities including appliances and human beings. It guarantees the compatibility of communication among different brand appliances. For system architecture, we proposed the distributed agent architecture. This architecture also guarantees that system developers can add new agents for appliances without redeveloping or rebuilding the whole system. We also proposed the layered architecture for agents, and it increases modularity to assist the extending the system. Additionally, we propose the bridge architecture to connect our system to different networks. It increases extensibility and reduces costs to building the systems. Finally we introduced flexible but simple XML message format for communication.

Our work on architectures and XML format helps to building extensible home automation systems. Based on the extensibility, it also helps to build compatible home automation systems and appliances.

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