JOURNAL OF INFORMATION SCIENCE AND ENGINEERING 29, 1227-1248 (2013)

DOI:10.1688/JISE.2013.29.6.10

Smart Door: A Ubiquitous Collaboration System for Home Activities in the Smart Home

YUAN-CHIH YU[1,3], SHINGCHERN D. YOU[1] AND DWEN-REN TSAI[2]
[1]*Department of Computer Science and Information Engineering*
National Taipei University of Technology
Taipei, 106 Taiwan
[2]*Department of Computer Science and Information Engineering*
[3]*Department of Information Management*
Chinese Culture University
Taipei, 111 Taiwan

This paper describes a smart home system consisting of Smart Door Porch and a home portal. Smart Door Porch uses cameras, an RFID (radio-frequency identification) reader, and a touch panel for home security as well as the at-home awareness of each family member. The home portal uses Open Services Gateway initiative (OSGi) framework and Java EE as the middleware to provide services including home activity, home calendar, and home collaboration map. The home collaboration map, based on the Google map, shows the locations of family members on the map with the aid of the GPS-enabled mobile devices carried by them. With the mobile devices, the proposed system supports ubiquitous collaboration among family members. Experimental results based on scenario simulations confirm that the proposed system is able to provide better services for family members in home collaboration.

Keywords: smart home, home collaboration, home activity, ubiquitous service, home calendar, home portal

1. INTRODUCTION

With the advances of technologies, the construction of a smart home has received wide attention, such as references [1-6] to name only a few. Among the existing papers, most of them focus on the technologies [5] and/or frameworks [2, 4] to be used within a home for tasks such as energy management [3]. This is not a surprising result. As pointed out by Bonino and Corno [1], the expectations of most users for a smart home system are comfort and taking care of household tasks. However, in our opinion, a smart home system should also include a service-oriented framework for easily extending more services. Furthermore, since the family members do not always stay inside "the indoor box" [7], it is a meaningful attempt to expend the service space outside the house. Therefore, this paper emphasizes more on providing ubiquitous services for family members to support their individual or collaborative activities.

For the purpose of gathering the location information of each family member, a smart home system has to know whether each family member is at home or not. With the at-home information, a smart home system, for example, can notify the family member to

Received August 1, 2011; revised November 24, 2011 & February 11 & March 16, 2012; accepted April 7, 2012.
Communicated by Jiann-Liang Chen.

leave home for an outside meeting if he/she forgets the meeting time and remains at home. Another example is that the smart-home system may turn off the stove or activate the surveillance system for security reasons if all family members are outside of the home. In both cases, the at-home information of each family member actually enables the smart home to provide better services.

To further extend the awareness of locations beyond home, we incorporated a mobile device with a GPS (global positioning system) receiver to obtain the location of each member even if he/she is away from home. Knowing the locations of the members, for example, helps the member at home ask which of the outside members can buy some milk on the way back home. With mobile devices, family members can also use the services provided by the smart home system to support home activities. Consequently, the collaboration among family members, *e.g.*, voting on the favorite restaurant for dinner, is not confined within the home, but can be at any place.

Although GPS-enabled mobile devices are widely used in the proposed system, the GPS information is not used to provide the at-home information as the GPS signal may be lost inside the home. Furthermore, elementary and secondary students may not be allowed to bring mobile phones to schools. Therefore, it is not appropriate to only rely on the mobile devices to obtain the at-home information. Another possible approach to detect whether all family members are out of home is by using motion sensors. Unfortunately motion sensors cannot provide the at-home information for individuals. By considering all these factors, we decide to use dedicate hardware around the door porch to provide the at-home information.

In this paper, we propose a smart home system containing a Smart Door Porch and a home portal. The Smart Door Porch supports the at-home awareness, whereas the home portal provides ubiquitous services for family members when they are away from home. The ubiquitous services, including the home calendar, home activity, and home collaboration map, partially rely on mobile devices to provide location information. Therefore, the mobile devices also built a client agent for system communication. Finally, with the integration from all the above components, the proposed system provides convenient services for ubiquitous collaboration among family members.

This paper is organized as follows. Section 2 provides some background information about related work. Section 3 describes the design of the smart door. Section 4 discusses the functions of the home portal for collaboration. Section 5 describes the experiments and results, including a comparison with the location-based social networking system. Finally, Section 6 is the conclusions.

2. RELATED WORK

The proposed system includes hardware setting and software infrastructure. The key elements of the system include Smart Door Porch, home portal, home collaboration, home calendar, and home middleware. The following gives a brief survey of the related work for each of the elements.

Yong *et al.* [8] propose a door lock system for smart home as a centralized main controller for the home automation system. The system consists of an RFID (radio-frequency identification) reader for user authentication, a touch-screen LCD (liquid-crystal display) panel as a visual interface, and various control and sensing modules for automated door operations and remote surveillance. A unique feature of their system is the ZigBee wireless network, which has the flexibility of not having infrastructures or planning. Their system inspires our development of Smart Door Porch. However, instead of developing an automated controller, our system takes the service-oriented requirements into account. Therefore, our system contains not only a controller but also a portal to provide services.

The middleware used in our system is based on OSGi (Open Services Gateway initiative) [9], which is widely used inside some home gateways [10, 11]. For example, Cheng *et al.* [11] use an OSGi-based communication portal for smart space to enhance the communication capabilities with various mobile devices. Lin *et al.* [10] combine Interactive Digital Television (IDTV) with OSGi platform. Basically, OSGi provides a service-oriented, component-based, lightweight environment for developers and offers standardized ways to manage the software lifecycle. However, the service-oriented architecture of OSGi simply focuses on the management of software components without supporting extension services. Therefore, some researchers try to integrate OSGi framework with Java EE [12] technologies to adopt Java EE's various enterprise-level frameworks [13, 14]. At present time, most of the J2EE frameworks are not compatible with OSGi, therefore some software teams are engaged in modularizing OSGi within Java EE frameworks [11, 13, 14]. In our Smart Door system, we use a bridge module to connect these two frameworks. Based on OSGi and J2EE, we use a portal framework in the proposed system to provide multiple interfaces for multi-agent collaboration. In addition, we also use J2EE framework to integrate different services and use Spring [15] to implement home activity. Summary of these works is listed in Table 1.

Table 1. The related works of OSGi service gateway integration.

References	Architectures	Application Domain	Related Technologies
Lin *et al.* [10]	MHP-OSGi collaboration	Interactive Digital Television (IDTV) and Residential Service Gateway (RG) convergence	OSGi, Xlet, HAVi-UI, JavaTV, JMF, *etc.*
Cheng *et al.* [11]	OSGi-Adapters portal	Communication Portal for Smart Space	OSGi, ECF, Directory Service, Web Service, *etc.*
Liu *et al.* [13]	OSGi-J2EE dynamic perception	Reconfigurable RFID middleware for Web presentation	OSGi DS, Struts, RFID middleware, *etc.*
Kaegi and Deugo. [14]	OSGI web application bridge approach	Building modular and evolvable server-side applications	OSGi, JSP, Servlet, *etc.*
Smart Door	OSGi-Spring-J2EE bridge portal	Ubiquitous home collaboration, Home activity support	OSGi, J2EE related, Smartphone, RFID, *etc.*

For visual presentation, Borodulkin *et al.* [6] propose a 3-D virtual user interface for smart home environment. Instead of using the virtual-reality technology, we represent the location-based information on the Google 2-D map [16], as its implementation is much simpler and more mature.

Nagel [17] explores the challenges of designing home availability services and activities, in which a cooperative design activity is used to identify which activities the family members are willing to share. In this regard, a home portal should provide home activity authoring interface in order to achieve the goal of sharing collaborative event. However, to design a family-based activity, a family member has to consider the locations of other members to figure out if they can attend the activity. That is one of the reasons that we add the Home Collaboration Map in our system.

To integrate services with location information, Suo and Shi [18] point out that the evolution of smart space can be divided into three stages: individual smart space, open smart space, and smart community. The first one is limited to a small space, such as a room. The second one supports the roaming of mobile devices and users may enter or leave the space. The third one is constructed by to connecting multiple open smart spaces. In our opinion, the smart home should support open smart space to achieve ubiquitous services. Therefore, we introduce the Smart Door Space before describing the proposed system. Jeng [19] emphasizes that the design of ubiquitous smart spaces requires collaborative efforts to integrate physical environments, digital infrastructures, and user experiences in a broader context of human-centered design. His concept is similar to ours in philosophy although our research focuses more on implementation issues and the model is designed for home activities.

One of the main topics in the development of smart space is the context-aware (*i.e.*, awareness of surrounding environment) collaboration. To this end, Park *et al.* [20] propose a context-based collaboration system with mobile devices. Steichen and Clarke [21] propose an application framework for scheduling mobile, context-aware activities. Although the mobile collaborative systems are subject to privacy issues [22], our system still heavily relies on the use of mobile devices for home collaboration. The privacy issue is ignored because the proposed system is to be used by family members.

A family usually has a home calendar shared by all members to coordinate activities. However, it is difficult to remotely access a paper calendar and to integrate multiple calendars [23]. Nowadays, web technologies offer the ubiquitous and pervasive accessibility for the calendar, which is not possible for the traditional paper one. Brush and Turner [24] list top challenges to use a digital calendar, such as forgetting to write things on a calendar, and so on. Neustaedter *et al.* [23] finds that ubiquitous access to the calendar increases the involvement of family members in the calendaring routine. He also emphasizes the importance of mobility − both within and outside of the home. To this end, our system supports remote access to the calendar in the home portal through mobile devices.

3. THE DESGIN OF SMART DOOR SYSTEM

The proposed Smart Door system is based on a conceptual model derived from a conceptual space, called Smart Door Space. In this section, we shall briefly describe Smart Door Space and the architecture and components of the proposed system.

3.1 The Smart Door Space

The Smart Door Space proposed in this paper has a logical and a physical dimension. The physical dimension is partitioned based on whether a family member is at home or not, whereas the logical dimension is partitioned based on whether a family member logs in to the system or not, as shown in Fig. 1. For the physical dimension, it is partitioned into Domestic Space (DS) and Non Domestic Space (NDS).When a family member is at home first and then leaves home, his/her status changes from DS to NDS. Therefore, DS and NDS are separated by the physical home door. The partition of the physical dimension is necessary in the sense of spatial awareness in ubiquitous computing applications – to know if a family member is indoor or outdoor. With the knowledge of member's location, the proposed system may invoke connections to remote devices, *e.g.* a mobile phone, if necessary. In the future work, the DS/NDS information will helps the system determine the actions of some smart devices in the house, such as activating the security alarming system if all members are in NDS.

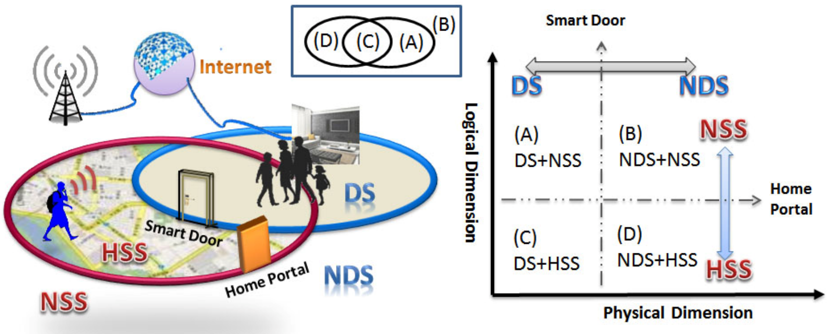


Fig. 1. Smart door space.

For the logical dimension, if a member logs in to the proposed system, he/she is in Home Service Space (HSS). If he/she logs out later, his/her status changes to Non Service Space (NSS). Such a partition is necessary in developing portal applications because the service interfaces for an authorized user would be different from that for an anonymous one. From the view point of providing services, the physical space should be independent of the logical one – the portal of system. For example, it is likely that a member is both in DS and NSS if he/she is at home and does not want to be served (bothered) by the system. A smart home should provide an option for members wishing not to be served. With this consideration, the physical and logical dimensions should be independent of each other. Thus, the Smart Door Space is partitioned into 2×2 subspaces, as also shown in Fig. 1, namely, DS+HSS, DS+NSS, NDS+HSS, and NDS+NSS.

In the proposed system, two types of processes are supported: home activity and home service. A home activity process registers an action involving one or more family members in home collaboration, and a home service process provides the basic infrastructure for executing an activity process. Each activity process has its own context (meta-data) to represent the related environment of the activity instance. The context can be modified and saved by any participant in the activity, not restricted to the original planner. This sharing feature enables home collaboration among family members. In the proposed system, a family member may define events and actions of an activity in advance, so the properties of the activity can be saved in the activity context. When a family member executes a pre-defined activity during run time, the system can group activities based on their physical dimension such as DS, NDS, or DS combined with NDS. For example, it is possible to group contexts of indoor (DS) activities for aggregating coherent concerns and common resources for better reusability and scalability. Another example is for outdoor (NDS) activities, where the common property among activities is that they all require location information to achieve ubiquitous collaboration.

3.2 Smart Door System

Based on the Smart Door Space, the Smart Door system has two sub-systems: a subsystem for door control and a home portal for application services. The former one is for the partition of the physical dimension, and the latter one is for the logical dimension. The door control subsystem, Smart Door Porch, provides not only basic home security but also the at-home status for family members when they pass through the main door. On the other hand, the home portal provides services to support family activities. In addition, the system also includes mobile devices for users to remotely access the portal.

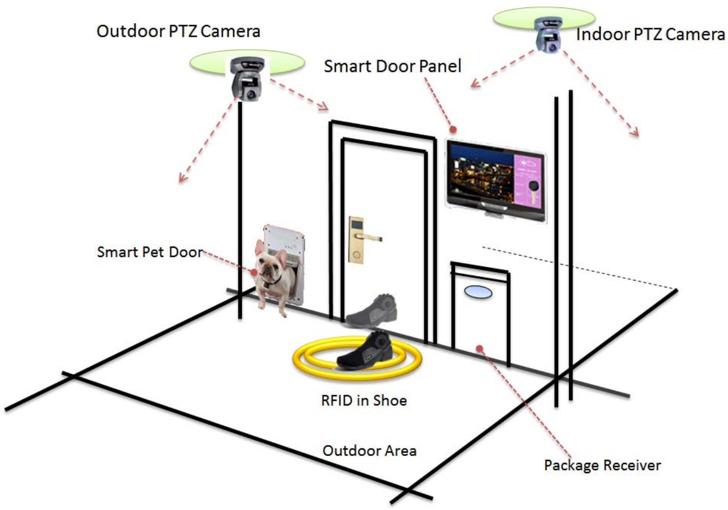


Fig. 2. Deployment of the smart door porch.

3.2.1 Smart door porch

The Smart Door Porch subsystem, as shown in Fig. 2, consists of an LCD touch panel, two PTZ (pan-tilt-zoom) cameras, an electronic lock, and an RFID reader. Optionally, the subsystem may also contain a smart pet door and a mailbox for receiving packages. The LCD panel, mounted on the outside wall of the house, serves as a virtual door key interface for opening the electronic door lock. It also provides additional information for guests such as the address of the house and the names of the family members. The cameras are located close to both sides of the main door to track if a person walks through the doorway and, if so, to identify the person. The video cameras also provide additional functions. Firstly, the outside camera is a part of the video intercom system to capture the image of the outside guest. Secondly, both of them serve as a part of the surveillance system when necessary. The RFID reader in front of the door reads the tag attached in a shoe worn on a member to help the system identify the person.

3.2.1.1 Detection of leaving home

When a family member leaves home, his/her face or body features are captured by the indoor camera first, and then the outdoor camera checks if the same person leaves. In addition, the RFID reader reads the information from the tag on the shoe as a supplementary identification. One of the reasons for using the RFID reader is that the correctness rate of a video-based recognition system is not sufficiently high with the current technology. The correctness rate is subject to environmental conditions such as poor lighting, occlusion, and so on. Even a high correctness rate is not sufficient because family members enter or leave the house in a high frequency. It becomes very inconvenient to frequently ask a member to provide his/her identity due to the failure of the face/body recognition. With the aid of the RFID tag, this problem is alleviated.

With the aid of RFID tags to provide the identity information, the cameras are used only to determine the direction of the family member, *i.e.*, entering or leaving the house. In the future, we also plan to add the face recognition capability into our system for higher degree of security. The algorithm to detect the leaving of a member is shown in Fig. 3.

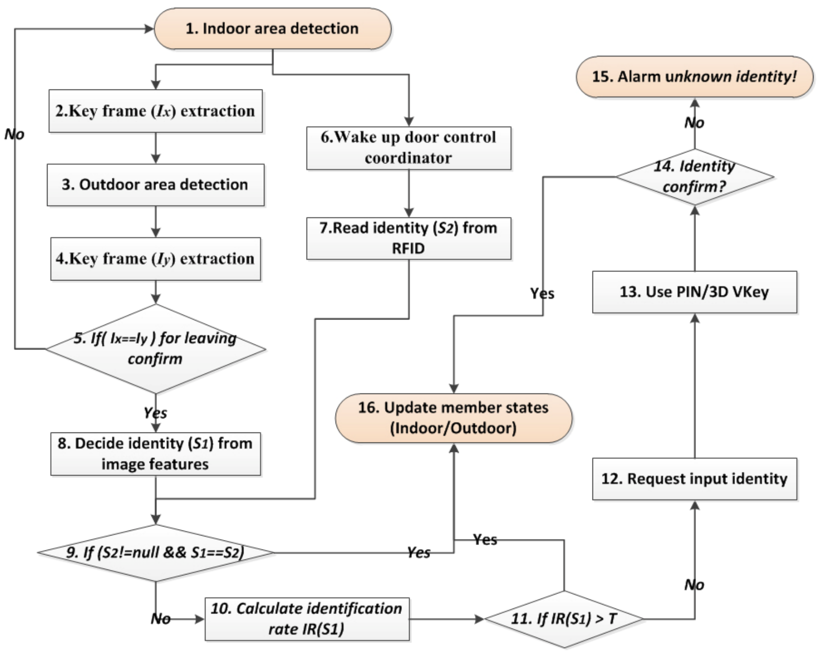


Fig. 3. Algorithm to detect the leaving of a member.

In steps 1, 2, 3, and 4, when someone goes out of the door, the indoor/outdoor video camera detects the motion of the image and captures the key frame images, denoted as I_x, and I_y, respectively. The key frame is chosen from a sequence of image frames. Since the background image is known when setting up the system, it is easy to detect a moving object. The key frame is the frame where the moving object reaches its maximum number of pixels in the sequence of frames. In step 5, by comparing I_x, and I_y the system confirms the leaving of the person. In this step, the image features of I_x, and I_y are the height of the body and the shape of the body. It is obvious that the body shape must be the same for both I_x, and I_y. Once the leaving action is confirmed, the door control coordinator sends a query to the RFID reader in steps 6 and 7. The reader reads the information of pass-through person's RFID tag, denoted as $S2$. In step 8, we compare I_x, and I_y with historical (and training) data to figure out the identity S_1 of the member. In steps 9 and 10, if $S2$ is available, we compare S_1 and S_2 as a second-layer confirmation. If these two do not match, identity S_1 is searched again based on the similarity between the contour of the unknown body and those of pre-stored ones. In step 11, if the similarity is greater than a threshold, which is experimentally determined, then S_1 is re-assigned. Because the back ground image is not changed, the threshold is not difficult to determine. If the identity of the member is unknown, in steps 12, 13, 14, 15, and 16, the coordinator issues an alarm sound and requests the person inputting the personal identification number (PIN) for identity verification. Alternatively, the member may use virtual 3D key (described in a subsection below) for this purpose. If the identity of the member is still unknown, the system goes to step 15 to inform the administrator. If the identity is known, the coordinator updates the indoor/outdoor states of the person and synchronizes this information to other processes, if necessary. Then, the process ends.

3.2.1.2 Detection of entering home

When a family member goes back home, he/she should use the virtual door key to open the door. However, for leaving, using the virtual door key is not necessary. When a guest arrives, he/she should touch the visitor button on the LCD panel as a digital door bell. If the guest is allowed to enter the house, the system will assign a visitor ID (identification) to the guest. In the meantime, the system also records his/her image from the outdoor video camera for later comparison when leaving.

3.2.1.3 Virtual door key

The idea behind the virtual door key is to relieve the burden of carrying real door keys. Although the proposed system has a face/body recognition system and an RFID reader, we still use the virtual door key to open the door for the considerations of human habits and home security. On the human habit side, most people customarily use keys to open doors. Therefore, when a person opens a door without using a key, he/she may worry that the door might be opened for any one, or even not locked at all. On the security side, the face/body recognition using a camera may fail due to bad lighting condition, occlusion, and so on. For the RFID system, the tag may be cloned [25]. Moreover, it is possible that a family member loses his/her shoes for various reasons. Considering all these factors, we decide to add the virtual door key in the proposed system. Since the virtual door key relies on the finger gesture to open the door, though not easily, it is still possible that the gesture is peeked and mimicked. To cope with this problem, the system may be set to open the door only if both RFID tag and finger gesture are correctly identified. In case that only the finger gesture is correct (no RFID), the system will pop out additional secret questions for the member to answer. With this arrangement, the security of the system is enhanced.

Without using keys, a security systems may use a keypad to input PIN (Personal Identification Number) for identification. In our system, however, we use finger gesture to replace the PIN for higher flexibility and security. To open the door, the user must drag the 3D virtual key, appearing on the multi-touch panel, along a specific path to a pre-defined location before turning it, as shown in Fig. 4. The pattern of the finger dragging can be individually configured and recorded for each member in advance. Thus, the finger movement of dragging the key forms a unique gesture pattern which may not be easily mimicked.

In order to reduce the computational burden, we use a simplified method to recognize the gesture pattern. In the present implementation, the touch screen is divided into six blocks. Before using the system, the user has to provide a set of basic gestures for recognition. As shown in Fig. 4, the pattern of a basic gesture is the trace of the finger movement over a block. The trace is obtained through a two-dimensional path of a single touch point over time. For managing purposes, each basic gesture pattern has an index number. When the user set up his/her personal gesture pattern to open the door, the pattern has to be a combination of the basic gestures. The overall gesture pattern is stored as the sequence of the indices of basic gestures. When the user moves the virtual key to open the door, the system uses a simple pattern matching algorithm to recognize the input gesture in a block. By comparing the index sequence of the current input pattern with that of the pre-defined one, the system determines whether the gesture is accepted or not.

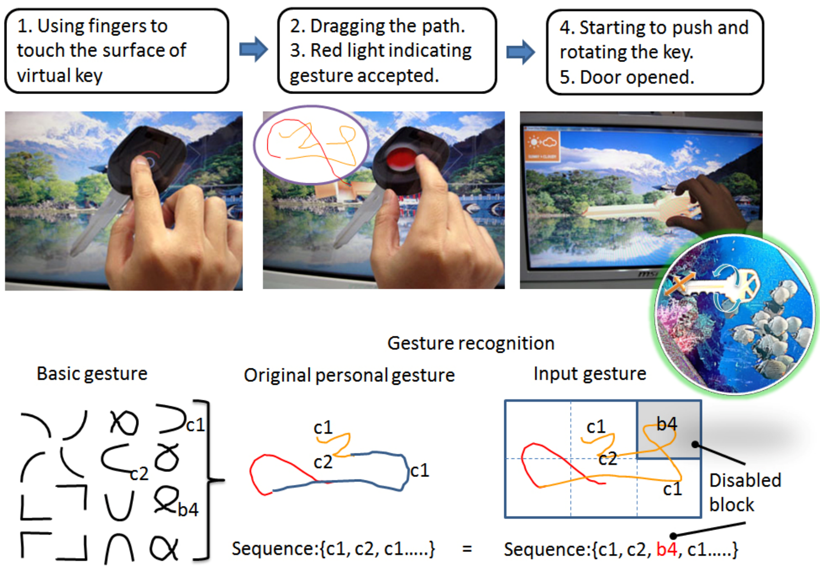


Fig. 4. Smart door key.

In addition, the user may enable or disable some blocks with weekday setting. The gesture pattern in a disabled block is discarded by the system. With such a design, the user may add fake finger-movements to confuse the peeper if necessary.

If a specific gesture to move the key is accepted, the member can then push the virtual key into the key hole and rotate it as if he/she were using a real key. Though not currently implemented, the depth of the virtual key inside the keyhole and/or the angle of key rotation may also form a secondary layer of encrypted code. For example, the user may turn the key one-and-a-half turn to the left, push one key tooth further in, and then turn right one-half turn. However, the push distance and/or the rotation angle should be identical for all family members since in real world every member keeps the same shape of physical door key. The virtual key should not violate this rule. In case when a member forgets the depth and the rotation angle to open the door, other members may remind him/her.

3.2.2 Home portal

The home portal provides the basic infrastructure for the application services in the system. To have a higher flexibility and extensibility, we use the widely adopted Eclipse OSGi Equinox [26] as the execution environment. Then, Equinox is deployed as a WAR (Web Application Archives) file in a Java EE application server through a servlet-bridge. By doing so, the portal is able to execute OSGi-based web applications in a servlet container. This design combines advantages of high availability and scalability provided by the Java EE application server environment and high flexibility and reusability by CODA (Component Oriented Development and Assembly) and Equinox. In our case, we use a Java EE application server with Spring framework [26] as the embedded servlet container. The Spring Framework has an Inversion of Control container, which provides a consistent means to configure and manage the lifecycles of Java objects.

Fig. 5 shows the layered model of the portal software. The presentation layer is a smart home portal built on top of other layers. The portal is a web framework suitable for

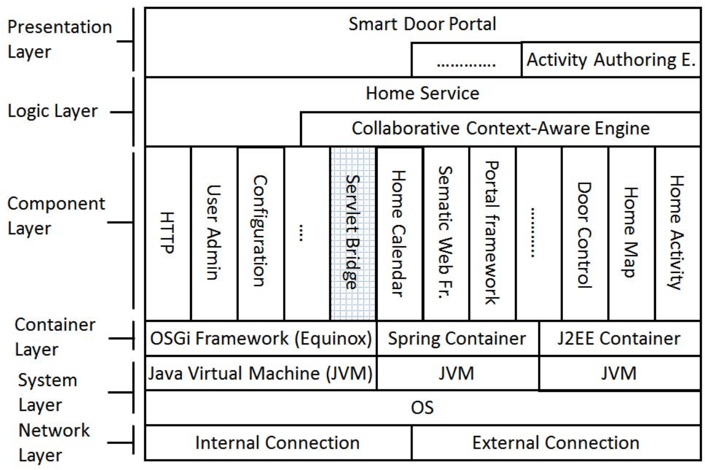


Fig. 5. Layered model for smart door portal.

users to customize and simplify the constructions of applications. The interfaces of the portal consist of system admin frame, service admin frame, activity admin frame, home calendar, and activity authoring frame. Below the presentation layer is the logic layer. This layer processes requests from presentation layer and performs reasoning and logic computing. By using the basic functions in the component layer, this layer forms a kind of home service for the presentation layer. The logical computing capability of this layer is provided by the collaboration context-aware engine. Based on the collaboration ontology [27], the engine can query the semantic meaning of home collaboration for the system to realize the information of home activities and to switch to correct Smart Door subspace.

In the component layer, we implement the functionalities of the system as modules including door control module, home map module, home calendar module, and home activity module. In addition, this layer also contains a module with OSGi built-in components and a bridge module for OSGi applications to be executed in the Java EE container. In our design, home calendar is a scheduling engine for dispatching and invoking home activities. We can view home calendar as a family-based personal digital calendar, and a home activity is an upcoming event. The container layer is implemented based on Spring framework with a Java EE container for aspect-oriented component development. Spring container includes a built-in portal sub-framework, known as Portlet MVC (Model-View-Controller) framework, based on JSR-286 (Java Portlet Specification 2.0) [28]. The Portlet MVC framework supports the execution of instances of home activities similar to a groupware system does. It has a strong capability of customizing the user interface and of role management. These features reduce the development efforts for the home portal, particularly for representing hierarchal roles of family members such as father, mother, child, and so on. Basic infrastructure of the system is in the system layer and network layer.

In the system layer, each of the three software containers is individually executed by a Java virtual machine (JVM) to reduce the implementation and management efforts. In the network layer, the architecture is built on the infrastructure of home network and Universal Mobile Telecommunications System (UMTS) network. As the gateway operator service is a built-in service in OSGi, we leverage it for the communications between the home network and internet.

3.2.3 Mobile agent for smart door

Since a family member may also need portal services when he/she is outside of home, we also implement an agent program in a mobile device to access the portal. The portal uses the http tunnel listener to parse the messages received from different member's mobile devices. Because the message passing route uses the http tunnel communication, it bypasses the firewall and gives an extra layer of protection against hackers, spyware, or ID theft with built-in encryption. With the mobile devices, the system is able to provide ubiquitous and continuous services. Because the device constantly attaches to the internet by the UMTS network, the agent program can periodically transmits the GPS information back to the home portal to report the current location of the family member. When the user enters into a house and the GPS information cannot be updated, then the mobile agent uses the last available location to be the present location. In this case, the mobile agent still provides location information without interruption. It is also possible to implement the mobile agent in such a way that it may fetch the information from the historical (or user-defined) database to indicate that the user enters into a house. This information will be useful for home collaboration.

By retrieving the location information collected in the portal, any member can display a collaboration map using a mobile device. As shown in Fig. 6, the agent program has a collaboration map to show the location of each family member. When the user selects a member on the screen, a dialog is shown for text, voice, or video communications. Moreover, the user can invoke a run-time activity for the selected member. The mobile device used in our implementation is a smart phone platform and the agent software is developed using the Android SDK R0.8 deployed on the android platform 2.2. The agent program can be installed either by a local installer or by a web installer downloaded from the portal for remote installation.

(a) Home collaboration map. (b) Communicate dialog. (c) Invoke a activity.

Fig. 6. Mobile agent on the mobile device.

4. HOME COLLABORATION

Home collaboration occurs in many different scenarios. Any work requires two or more members being involved is considered as a type of home collaboration. Family members vote on a favorite restaurant for dinner is one example of home collaboration. To aid members, the system sends messages to mobile devices for members in NDS, and the members may respond the poll using their mobile devices. Another example is that a family member requests any member close to a grocery store to buy a bottle of milk on the way back home. In this case, it is very handy to have the location information of each outside member. To better serve the members, we use a home portal to provide services. Therefore, services link the members and their activities for collaboration works.

4.1 Home Calendar and Home Activities

When a family member connects to the portal, he/she uses his/her personal working area, with a customized layout for personal setup, to add scheduled activities. The (user) interface of the home calendar provides time slots to define conditional events for an activity. When the scheduled time for an activity reaches, the home calendar invokes an activity instance to run. Therefore, the home calendar plays a role as the system's heart-beat in the sense that it coordinates all the time-dependent activities and monitors the location of each member. The snapshot of the home calendar interface is shown in Fig. 7a, which is an Adobe Flex application running as a flash component for the portal web page. To use the calendar, the user drags and drops a time slot on the screen to schedule the selected activity. To check the calendar, the user may click the time slot at any time to view the state of progress.

To assist home members with collaborative activities, the portal supports two types of activities: routine and one-time-only activity. The portal has an activity authoring tool for members to construct a template, called activity template, for routine activities. With the constructed templates, the member only needs to configure the parameters of the template to start a run-time instance. As Fig. 7 (b) illustrated, the workspace on the activity authoring environment has an activity plate, a service plate, a scope calendar, a node property panel, and an activity composition panel. In the activity composition panel, the member treats one activity step in a sequence as node, and then links each node with branches. For each node, he/she may also define the time rule, the participating members, the constraint of the locations, and the related events or service. After completing the design, it becomes an activity template for all members to repeatedly use. To invoke the routine activity, the member uses the home collaboration map (to be described in the next subsection) to know the locations of the members, and then selects the activity template for the assigned members directly. In the meantime, he/she may adjust the time sequence for the nodes of activity and assign each node with pre-conditions and/or post-conditions.

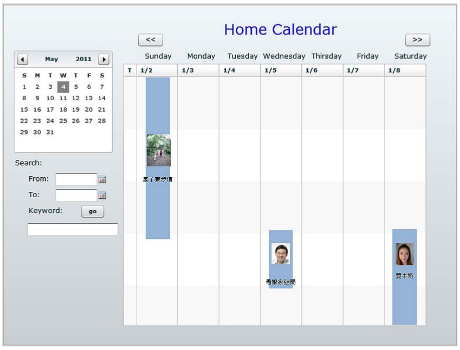


Fig. 7. (a) Home calendar.

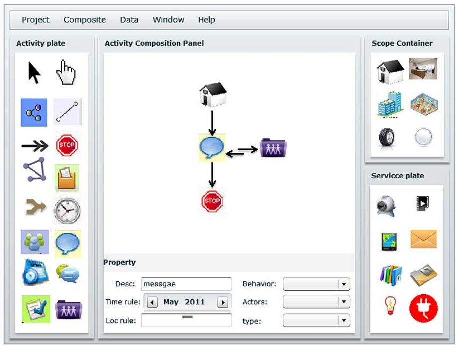


Fig. 7. (b) Activity authoring tool.

In contrast to the routine activity, the one-time-only activity does not need to use the pre-authoring activity templates because this type of activities often happens unpredictably. Therefore, repeatedly configuring templates is a tedious and annoying work. For one-time-only activities, a member may use home collaboration map to, for example, activate a video call. Alternatively, he/she may assign an activity to a selected member directly, as in the example of "buy milk on the way home" mentioned previously. Inside the portal, every activity contains state information and, when necessary, the information can be handed over to other activities for activity synchronization.

The home activity is managed by the Spring Inversion of Control (IoC) container [15], also known as dependency injection (DI). In Spring, the managed objects are called beans. A bean is an object that is instantiated, assembled, and otherwise managed by the Spring container. Based on the lifecycle of bean, we extend the logic states of home activity into the lifecycle of home activity. Therefore, there are five states in the life cycle, as shown in Fig. 8.

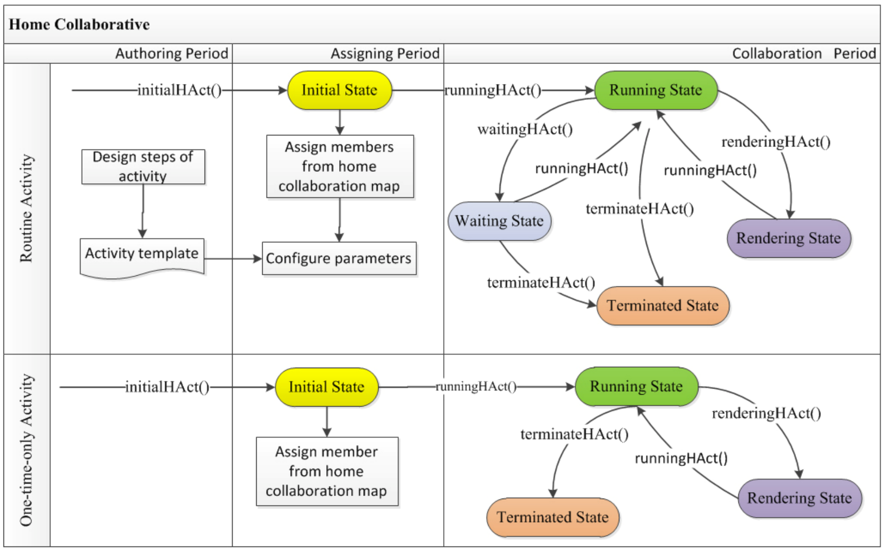


Fig. 8. The life cycle of home activity.

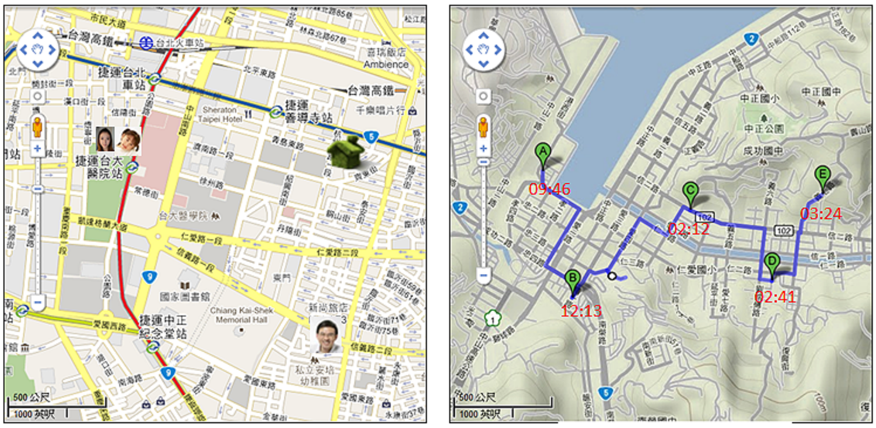
1. Initial state: The activity is configured by the invoker using the activity authoring tool. The configuration of the activity includes the setup of parameters, the members involved, the editing of nodes, and so on.
2. Rendering state: The activity is in the foreground of the screen and has the user focus. When the activity is in the rendering state, members can communicate with each other by text/video/voice interfaces.
3. Running state: The activity is running in the server for computing jobs, such as logging state information, and message conversion.
4. Waiting state: The activity is still alive, but it persists the session of activity into the persistence storage, waiting for re-initialed. It can be terminated by the system in time-out situations. However, when the activity is re-started again, it must be re-initialed to update new context information.
5. Terminated state: The activity is considered as complete if the activity is finished, terminated by a user, or expired.

A routine activity is in one of the five states mentioned above. However, the one-time-only activity does not the "waiting state" because the activity is invoked by real-time communication such as a video/voice call. The activity directly enters into "rendering state" when the initialization work is finished. Because a one-time-only activity involves only two participants, it does not need to design the collaboration steps in advance. In Fig. 8, the time axis is divided into three periods. The collaboration period is the time of activity execution. The authoring period is the time when activity templates are designed. The assigning period is the time when the system informs each remote participant with his/her smart phone. If the assigned member is not available, the activity enters the "waiting state" and the situation is to be resolved by the invoker later.

We use the case "buy some milk on the way back home" to explain the transition of activity states. After the invoker, say, mother, configures the activity and picks the member to buy milk, the activity goes into the "Initial state". When the conditions are fulfilled, the container callback the runningHAct() of activity instance to execute the "Running state." If the dialog between members needed, the container calls back the rendering-HAct() to render the interface for communications. After the communications, the activity goes into the "Running state" by calling runningHAct(). On the other hand, if the assigned member is not available, the activity goes into the "Waiting state" for invoker to resolve the problem. The logic of resolving the waiting state is embedded in the waitingHAct(). When the assigned member responses to the system of finishing the job, the terminateHAct() be called to terminate the activity.

4.2 Home Collaboration Map

The main purpose of the home collaboration map is to represent the geographical locations of family members on a map. The location-aware capability of the portal is accomplished with the aid of GPS-enabled mobile devices to collect the locations of the members, as described previously. Since the map is based on Google Map API, it provides additional geo-information, such as nearby shops, hospitals, restaurants, or bookstores. With the home collaboration map, the user may assign a run-time activity to a specific member based on the consideration of his/her location. Fig. 9 (a) and Fig. 6 (a) illustrate the use of the home collaboration map on the portal and on the mobile device.



(a) Home collaboration map in web. (b) Activity topology.

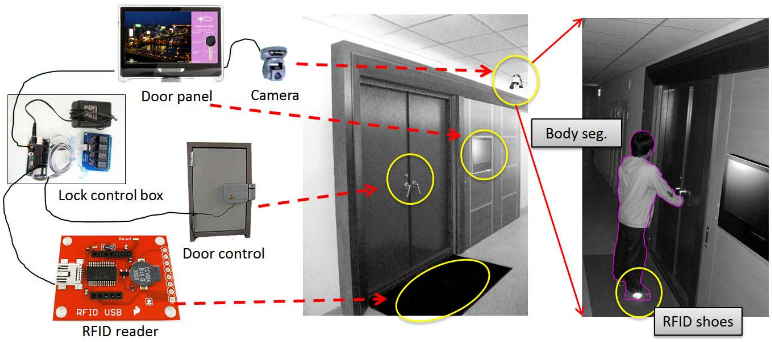
Fig. 9. Home collaboration map.

The home collaboration map also provides the locomotion path of an activity for further reference. Fig. 9 (b) shows the path of a tour activity from point A to point E. The path may be helpful if a member is lost.

5. EXPERIMENTS AND EVALUATIONS

5.1 Experimental Setup

To validate the concept of the proposed smart door portal, we implement an emulation environment, including one electronic door lock, one front door panel (multi-touch screen connected to a PC), two network cameras (2M pixels with Ethernet support), one USB RFID reader (125kHz ID tag, 32-bit ID), a pair of shoes attached with RFID tags, and one USB lock control box. The deployment of the experimental environment is shown in Fig. 10. The environments for the deployment of these programs are heterogeneous, and therefore development and installation of the programs are complicated.



(a) (b)

Fig. 10. (a) Experimental environment. (b) Identification of a member.

5.2 Home Collaboration Key Performance Indicator

To have a quantitative evaluation of the proposed system, we introduce the metrics of Collaboration Breath (CB) and Collaboration Depth (CD). These metrics are inspired by the innovation metric proposed by Choi and Ko [29], but with different definition. In our case, CB represents the frequency (number of times) a member is involved in a work, whereas CD is the total time a member spends on the work. For a fair comparison, the values of CB and CD are normalized.

The following uses our scenario of "voting on the favorite restaurant for dinner" as an example to describe how to obtain the values of CB and CD. Firstly, the mother uses the portal to start an activity. She is involved in the work once with an operation time of t_1. If two of the members away from home use their mobile devices to answer the vote, then each of them are also involved in the work once, with respective time of t_2 and t_3. Finally, the mother checks the portal to know the voting results. She is involved in the work once more with a time of t_4. In this scenario, the mother is involved in the work twice with each of her children once. Thus, the CB of the mother is 2/4 = 0.5, whereas that of each of the children is 1/4 = 0.25. Similarly, the mother has a CD value of $(t_1 + t_4)$ $/ \sum_{i=1}^{4} t_i$, whereas their children have CD values of $t_2 / \sum_{i=1}^{4} t_i$ and $t_3 / \sum_{i=1}^{4} t_i$, respectively. If the mother does not use the proposed system and makes two phone calls to her children with durations of t_1 and t_2 to determine the restaurant, she and her two children are involved in the activity only once. Thus, CB is 1/3 for each of them. When talking over the phone, the mother and one of the children individually spend time. The overall time spent among all members, therefore, is $2 \cdot (t_1 + t_2)$. The CD value of the mother is then 0.5 and those of her children are $t_1/(2t_1 + 2t_2)$ and $t_2/(2t_1 + 2t_2)$, respectively.

Based on CB and CD, we may define Home Collaboration Key Performance Indicator (HCKPI) for activity k as

$$\text{HCKPI}_\text{k} = \sum_{n=1}^{M} b_{k,n} \cdot t_{k,n}, \tag{1}$$

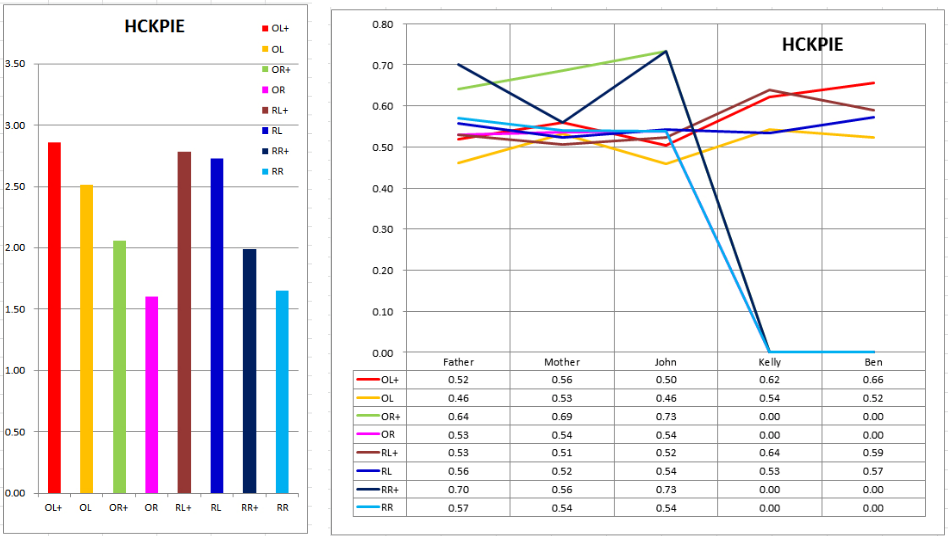
where $b_{k,n}$ and $t_{k,n}$ are the CB and CD values of person n in activity k, and M is the number of members involved in the activity. Based on HCKPI in Eq. (1), we further compute its entropy, called *HCKPIE*, as follows

$$\text{HCKPIE}_\text{k} = -\sum_{n=1}^{M} p_{k,n} \log(p_{k,n}), \tag{2}$$

where $p_{k,n} = b_{k,n} \cdot t_{k,n}$ and log is a base-2 logarithm. The above equation follows the definition of entropy in information theory [30] to measure the uncertainty of an event. In theory, if all $p_{k,n}$ have the same value for a given k, then entropy reaches its maximum. In our case, a higher value of HCKPIE indicates that the work is more evenly distributed among the participants. In the sense of collaboration, higher KCPPIE is preferable.

5.3 Experiments and Results

For system evaluation, we prepared four types of scenarios for simulation, which mainly corresponds to the physical dimension of Smart Door Space: one-time-only local activity (OL) for DS, one-time-only remote activity (OR) for NDS, routine local activity (RL) for DS, and routine remote activity (RR) for NDS. Also, the four scenarios are mapped into two types of activities: one-time-only or routine. The family in this simulation has five members: father, mother, two boys, and one girl. Each scenario is repeated five times in different weekdays during one month with (indicated by "+") or without using the proposed system. When scenarios evaluated without using the proposed system, the family members use mobile devices with oral communications as a control group. In this case, the collaboration among family members is achieved by traditional means such as phone calls or e-mails. For instance, without using the collaboration map provided by the proposed system, a family member may inquire the location of each family member through phone calls. Besides, the automatic message routine in the activity can be replaced by e-mails or faxes.



	Father	Mother	John	Kelly	Ben
OL+	0.52	0.56	0.50	0.62	0.66
OL	0.46	0.53	0.46	0.54	0.52
OR+	0.64	0.69	0.73	0.00	0.00
OR	0.53	0.54	0.54	0.00	0.00
RL+	0.53	0.51	0.52	0.64	0.59
RL	0.56	0.52	0.54	0.53	0.57
RR+	0.70	0.56	0.73	0.00	0.00
RR	0.57	0.54	0.54	0.00	0.00

(a) HCKPIE of each activity. (b) Each component, *i.e.*, $p_{k,n}\log(p_{k,n})$, of HCKPIE for each activity.

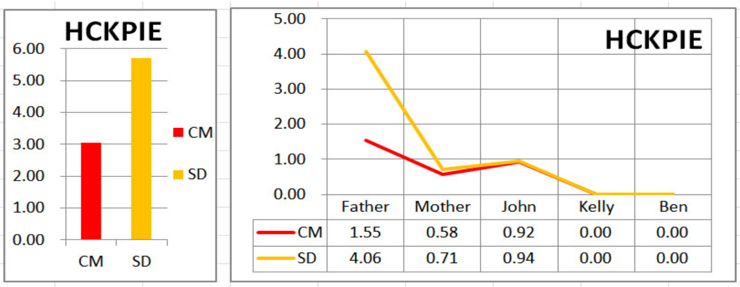
Fig. 11. Simulation results.

Fig. 11 plots the HCKPIE and lists the average values of $p_{k,n}\log(p_{k,n})$ for each member. Fig. 11 shows that the HCKPIE values are higher with the proposed system. Therefore, it is likely that family members have relative fair shares of the work load with the proposed system. One possible reason for this situation is that without using the proposed system, one of the members (*e.g.* mother) is likely to spend much more time to arrange, say, a favorite restaurant than other members do. This leads to lower HCKPIE. Fig. 11 also indicates that the one-time-only activities have larger HCKPIE differences. It indicates that it is more difficult to evenly distribute the work of a one-time-only activity into all participants without using the proposed system. For example, with the proposed system, it is easier for the mother to monitor the locations of the family member and to assign one of them to buy a bottle of milk on the way back home. Without the proposed system, the mother may have to make several phone calls to find locations of other members before assigning the task. The curves of OR+, OR, RR+, and RR reveal that Kelly and Ben cannot participate in the remote home collaboration and therefore have zero values. It is because, for example, a parent plans to go shopping and asks his/her children to provide their shopping wish list. As some children are in the schools, they are unable to respond at that time.

5.4 Comparison with Location-Based Social Networking Services

Recently, location-based services have been applied to social networking applications. For example, the Check-in Map App [31], executed in a GPS-enabled mobile device based on the Check-in function [32] of the Facebook, is able to collect the geolocation information of one's friends if they "check-in" to the Facebook. With the location information, the Check-in Map App is able to show on a map the current location of a user as well as the traversing line of his/her past check-in locations. As a result, such a location-based service may be used for home collaboration scenarios. Thus, it is worthwhile to compare the relative benefits of such a service with our proposed system.

For the comparison, the chosen scenario is "asking one of the family members to buy a bottle of milk on the way back home," as this scenario requires location information. In this scenario, we assume that the mother calls the father first, but he is unavailable. Then, the mother calls John and he accepts the job. The experimental results are given in Fig. 12, which shows that the Smart Door System (SD) has a higher HCKPIE than Check-in Map App (CM) has. Though seems surprising, the results are easy to understand. In the CM case, when the mother needs a family member to buy milk, she logs in to the Facebook and browses the most recent check-in locations of family members. Since the father is close to a grocery store, she calls him to do the job. As in the scenario, he is unavailable. Therefore, she has to view the map again in order to select another member, and then calls the member to learn if he/she accepts the assignment. This trial process may repeat several times. In contrast, in the SD case, the task of job assignment is accomplished with the provided tool, which integrates a map with a communication dialog interface to handle SMS, voice/video call, and so on. In addition, the home calendar function also helps to find a candidate. When a member has a predefined event (likely unavailable) in the present time, the communicating dialog will show the scheduled information for the user.



(a) HCKPIE of two systems. (b) Each component, *i.e.*, $p_{k,n}\log(p_{k,n})$, of HCKPIE for each system.
Fig. 12. Simulation results.

There are some potential issues when using the Check-in Map App. First, the App renews the locations information only if the user submits the "check-in" place. It is possible that a member forgets to check in. In our system, the location information is automatically collected on the background to avoid the "uncheck-in" problem. Second, a location-based system usually does not support all types of family activities, such as the scenario of "voting on the favorite restaurant for dinner" because home collaboration does not entirely depend on the location information. In fact, most of home collaboration scenarios depend on the type of home activity, but not on the location-based information or social network. Third, privacy is always a concern when using a public service such as Facebook. When using the Facebook, it is possible that, due to improper setting, private information is available to general public. There is no such concern if a proprietary system, such as the proposed system, is used. Judging from the experiments and the above discussions, we believe that the proposed system has its benefits in home collaboration over a location-based social networking service.

6. CONCLUSIONS

We propose a Smart Door system in this paper. The system consists of a Smart Door Porch and a home portal. The Smart Door Porch, other than door security, provides the awareness of at home status for each member. The home portal provides services for home collaboration including home calendar and home collaboration map. As smart phones are widely available nowadays, we also integrate them into our system for access the portal and for providing the location of each family member if going out. We implement an emulation environment to evaluate the proposed system. The experimental scenarios include different local and remote activities. To quantitatively evaluate the performance of the proposed system, the experimental results are presented using HCKPIE as a metric. The results confirm the effectiveness of the proposed system. We also discuss the advantages of using the proposed system over a location-based social networking service. Overall, the capabilities of the system provide better services in all types: one-time or routine activities in domestic or remote locations.

The proposed system is built based on the OSGi platform, which is a popular middleware for smart home systems. Therefore, the proposed system can serve as a starting point toward a more sophisticated and complete smart home system. Currently, the proposed system focuses on the service-oriented architecture for a smart home. It will be a meaningful step to further incorporate human-centered computing technologies into our system.

REFERENCES

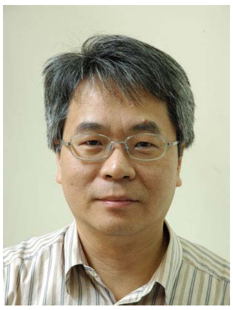
1. D. Bonino and F. Corno, "What would you ask to your home if it were intelligent? Exploring user expectations about next-generation homes," *Journal of Ambient Intelligence and Smart Environments*, Vol. 3, 2011, pp. 111-126.
2. K. J. Turner, "Flexible management of smart homes," *Journal of Ambient Intelligence and Smart Environments*, Vol. 3, 2011, pp. 83-109.
3. D. M. Han and J. H. Lim, "Design and implementation of SOAP-based residential management for smart home systems," *IEEE Transactions on Consumer Electronics*, Vol. 54, 2008, pp. 453-459.
4. C. Leong, A. R. Pamli, and T. Perumal "A rule-based framework for heterogeneous subsystems management in smart home environment," *IEEE Transactions on Consumer Electronic*, Vol. 55, 2009, pp. 1208-1213.
5. D. Ding, R. A. Cooper, P. F. Pasquina, and F.-P. Lavinia, "Sensor technology for smart homes," *Maturitas*, Vol. 69, 2011, pp. 131-136.
6. L. Borodulkin, H. Ruser, and H. R. Trankler, "3D virtual 'smart home' user interface," in *Proceedings of IEEE International Symposium on Virtual and Intelligent Measurement Systems*, 2002, pp. 111-115.
7. M. Mokhtari, M. Ghorbel, R. Kadouche, and M. Feki, "From smart home to smart space in independent living: a framework for multiple contexts management," in *Proceedings of the 3rd IEEE International Conference on Wireless and Mobile Computing, Networking and Communications*, 2007, pp. 74-74.
8. Y. T. Park, P. Sthapit, and J. Y. Pyun, "Smart digital door lock for the home automa-

tion," in *Proceedings of IEEE Region 10 Conference*, 2009, pp. 1-6.
9. OSGi: Open Service Gateway Initiative, http://www.osgi.org/, 2012.
10. C. L. Lin, P. C. Wang, and T. W. Hou, Classification and revaluation of middleware collaboration architectures for converging MHP and OSGi in a smart home," *Journal of Information Science and Engineering*, Vol. 25, 2009, pp. 1337-1356.
11. C. Cheng, Y. Suo, Y. Chen, Y.C. Shi, and W. K. Yang, "SSCP: An OSGi-based communication portal for smart space," in *Proceedings of Joint Conferences on Pervasive Computing*, 2009, pp. 309-314.
12. J2EE: The Java 2 Platform, Enterprise Edition, http://java.sun.com/j2ee, 2012.
13. F. Liu, W. Shen, K. Lin, and Y. Zhang, "Modulization approach & application of OSGi-based RFID middleware web presentation layer," in *Proceedings of International Conference on Anti-counterfeiting*, *Security*, *and Identification in Communication*, 2009, pp. 266-271.
14. S. R. Kaegi and D. Deugo, "Modular Java web applications," in *Proceedings of ACM Symposium on Applied Computing*, 2008, pp. 688-693.
15. Spring: an open source application framework for the Java platform, http://www.springsource.org/, 2012.
16. Google mobile map, http://www.google.com/mobile/maps/, 2012.
17. K. S. Nagel, J. Y. Sung, and G. D. Abowd, "Designing home availability services," *Pervasive and Ubiquitous Computing*, Vol. 11, 2007, 361-372.
18. Y. Suo and Y. Shi, "Towards initiative smart space model," in *Proceedings of International Conference on Pervasive Computing and Applications*, Vol. 2, 2008, pp. 747-752.
19. T. Jeng, "Toward a ubiquitous smart space design framework," *Journal of Information Science and Engineering*, Vol. 25, 2009, pp. 675-686.
20. W.-I. Park *et al.*, "A context-based collaboration system in ubiquitous environments," in *Proceedings of International Conference on Convergence Information Technology*, 2007, pp. 101-107.
21. B. Steichen and S. Clarke, "Wireless collaboration for context-aware services using mobile networked applications," in *Proceedings of International Conference on Wireless Communications*, *Networking and Mobile Computing*, 2008, pp. 1-9.
22. J. Hakkila and J. Mantyjarvi, "Collaboration in context-aware mobile phone applications," in *Proceedings of the 38th Annual Hawaii International Conference on System Sciences*, 2005, pp. 33a.
23. C. Neustaedter, A. J. Brush, and S. Greenberg, "A digital family calendar in the home: lessons from field trials of LINC," in *Proceedings of Graphics Interface*, 2007, pp. 199-206.
24. A. J. Brush and T. C. Turner, "A survey of personal and household scheduling," in *Proceedings of International ACM SIGGROUP Conference on Supporting Group Work*, 2005, pp. 330-331.
25. J. Kim and H. Kim, "Security vulnerability and considerations in mobile RFID environment," in *Proceedings of the 8th International Conference Advanced Communication Technology*, Vol. 1, 2006, pp. 801-804.
26. Equinox: an implementation of the OSGi R4 core framework specification, http://www.eclipse.org/equinox/, 2012.
27. F. F. Oliveira1, J. C. P. Antunes, and R. S. Guizzardi, "Towards a collaboration on-

tology," in *Proceedings of the 2nd Workshop on Ontologies and Metamodels in Software and Data Engineering*, 2007.
28. JSR-286: Portlet Specification 2.0, http://www.jcp.org/en/jsr/detail?id=286, 2012.
29. G. Choi and S. S. Ko, "An integrated metric for R&D innovation measurement," in *Proceedings of Technology Management for Global Economic Growth*, 2010, pp. 1-5.
30. C. E. Shannon, "A mathematical theory of communication," *Bell System Technical Journal*, Vol. 27, 948, pp. 379-423 (part 1), 623-656 (part 2).
31. Facebook Check-in Map, http://apps.facebook.com/checkinmap, 2012.
32. Facebook CheckPoints, http://www.facebook.com/CheckPoints , 2012

Yuan-Chih Yu (游源治) received the Ph.D. degree in the Department of Computer Science and Information Engineering, National Taipei University of Technology, Taipei, Taiwan, in 2013. He is now an Assistant Professor in the Department of Information Management, Chinese Culture University. His research interests are in the areas of smart environment, pattern recognition, affective computing and software architecture.

Shingchern D. You (尤信程) received the Ph.D. degree in Electrical Engineering from the University of California, Davis, CA, USA in 1993. Currently, he is an Associate Professor in the Department of Computer Science and Information Engineering in the National Taipei University of Technology, Taipei, Taiwan. Dr. You's research interests include audio signal processing and recognition, applied digital signal processing to communication systems, and intelligent systems.



Dwen-Ren Tsai (蔡敦仁) received the Ph.D. degree in Computer Science from City University of New York in 1990. He was an Information System Assistance Professor at Stockton State College, New Jersey, USA, from 1990 to 1993. He has been an Associate Professor of Computer Science at Chinese Culture University in Taiwan, since 1993. He has also been the Chair of Computer Science Department of CCU since 1998. His areas of interest include computer security, software engineering, management information system, and digital archiving.