Open Smart Classroom: Extensible and Scalable Smart Space Using Web Service Technology*

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Abstract. Real-time interactive virtual classroom with tele-education experience is an important type of distance learning, while the current available systems are not able to connect different classrooms in open network for intercontinental and intercultural learning. Open Smart Classroom, which is an upgrade learning system based on Smart Classroom using Web Service technology, provides more extensible and scalable features to tackle the new requirements and challenges of distance learning. Open Smart Classroom is developed based on Open Smart Platform, the software computing infrastructure for Smart Space, which provide three new features: 1) open and standard interface for better mobile devices connection and communication without any prior configuration; 2) open services invocation channel between inside modules and outside systems 3) open network in which multiple Smart Spaces can connect and communicate with each other. Making use of these new features, Open Smart Classroom shows a novel and interesting experience to both of the teachers and students for intercultural and intercontinental distant learning, which also gives a significant research perspective of future distance blended learning system.

Keywords: Pervasive Computing, Smart Space, Web Service.

1 Introduction

With the rise of a new generation of web-based learning system, traditional learning mode, where teachers and students are face to face with each other in the same classroom, however, still has its unrivaled advantages. Therefore, how to use the new methods and technologies raised by pervasive computing and Smart Space to enhance the effectiveness and experience becomes a very important topic of learning system. Many works have been done to address this problem, such as Tsinghua University's Smart Classroom [17], ActiveClass [11], Class Talk [3], which are all seeking for

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better teaching and learning mode based on traditional face to face classroom learning. Especially, Smart Classroom adopts the blended learning way, implementing multiple modalities and human-computer interfaces to provide a tele-education experience similar to real classroom experience, which gives both of the remote and local students more natural experience on learning.

Smart Classroom is a Smart Space [19] on tele-education, which beyond the traditional classroom, working on pervasive/ubiquitous computing mode. Enabling the remote students to participate the traditional classroom education makes Smart Classroom an open classroom. However, as the trend of pervasive computing developing requires Smart Space to be more and more open, Smart Classroom is facing new requirements and challenges.

– Open interface for mobile devices to communicate better.

To support mobile devices communications is one of the requirements of learning system. Researchers in [5][12] emphasize that mobile devices play an important role in computer-supported collaborative learning. For example, the teacher uses his Smart Phone to bring the presentation file and control the slide show, while the students can use Laptop to discuss some problems with others. Several projects have partially taken into account of this issue. Active Class enables the students to use mobile devices to give feedback to the teacher, while the students cannot use it to invoke other classroom interfaces, such as PPT control interface, to control the devices and applications of the class. Smart Classroom supports mobile devices joining in and interacting with existing applications and devices [4], but it requires mobile devices to install the mobile driver program of Smart Platform (the software infrastructure for Smart Classroom) and pre-developed applications. With the mobile device developing, it is unfriendly and inconveniently to ask the users to install the specific driver program when they bring their device into Smart Classroom. Also, building those driver programs is complex and labored work because there are so many different system of mobile devices, such as Windows CE, Palm, Symbian OS, Linux and so on. Therefore, it shows the necessity that standard and open mobile devices communication interface should be built, which enables mobile devices to join in, control and interact with class without any prior configuration.

– Open services invocation channel between inside and outside.

How to enable services invocation between inside modules and outside system of Smart Space (maybe another system of Smart Space) while keeping it easy and standard is the second challenge. Smart Space is becoming more and more open, which gives the chance for the blended learning system to be more open. There are abundant services resources in the open network for the learning system to use, while some outside system may require of invoking inside services of the learning system. For example, the mobile company or Smart Classroom A want to dynamically find out whether the student attends the Class B, which is a service provided by Smart Classroom B. Current Smart Space related project, such as iRoom [2] and Smart Classroom, the services provided by modules can be invoked very easy by other modules inside of the Smart Space. However, it is not so easy to invoke outside services which do not belong to Smart Space. Neither of the outside system invokes the services inside of Smart Space. Therefore, creating well service invocation channel between

inside and outside of Smart Space is very important and also useful to elevate the function of the class.

– Open network in which multiple classrooms connect.

The third challenge is to support multiple classrooms to connect with each other through intercontinental WAN and have classes together. As the increasing requirement of intercultural and intercontinental communication and learning, enabling remote students to participate in class of Smart Classroom and easily communicate with teacher and local students is not enough. Addressing two or several real-time interactive classrooms to connect with each other should be one of the aims of future distance learning systems. Moreover, because of the evitable difference among these connected classrooms, necessary transformation is needed. For example, the classroom in Kyoto University may use Japanese while the one in Tsinghua University may use Chinese. Simply connecting these two classrooms will cause misunderstanding because of different languages. Therefore, the robust translation service with highly accuracy, or other involved mechanism for intercultural communication should be taken to make the people in these classrooms understood. This simultaneously synchronous intercultural teaching mode, that multiple classrooms having one class with automatically translation features, has long-term significance for the research of intercultural learning and communication.

According to the three challenges showed above, based on Smart Classroom, we present Open Smart Classroom which not only well supports personal mobile device interactions but also implements the mechanism enabling multiple classrooms to connect with each other in the open network. Moreover, since the established service invocation channel between inside and outside of Smart Classroom, Open Smart Classroom provides its own services ontologies and utilizes the abundant web services. The service ontologies are used by outside system for better extensibility and workflow design modules for better scalability. The machine translation web service is used to transform the texts content in the classrooms for better intercultural and intercontinental understanding.

To implement Open Smart Classroom, we design and develop the software infrastructure Open Smart Platform, which greatly extends the function and ability of Smart Platform [15]. To adapt the challenges given by Open Smart Classroom, Open Smart Platform adds new modules and involves new criterion, so as to give better software infrastructure support for Open Smart Classroom and other future projects in Smart Space.

In this paper, we explore three successive phases of Smart Space and several related learning systems and software infrastructure in Section 2. Section 3 introduces the architecture, new features and implementation of Open Smart Platform. Section 4 explains the design of Open Smart Classroom and validation scenarios. Section 5 draws the conclusion and presents future work.

2 Background and Related Work

With the development of Smart Space, we propose three successive phases of Smart Space: *Individual Smart space, Open Smart Space* and *Smart Community*, as Figure 1.

The three phases are listed in logical order rather than temporal order, where new problems added continuously from the left to the right. Modulate symbol connecting each phase represents that new problems added on previous phase make it much more complex.

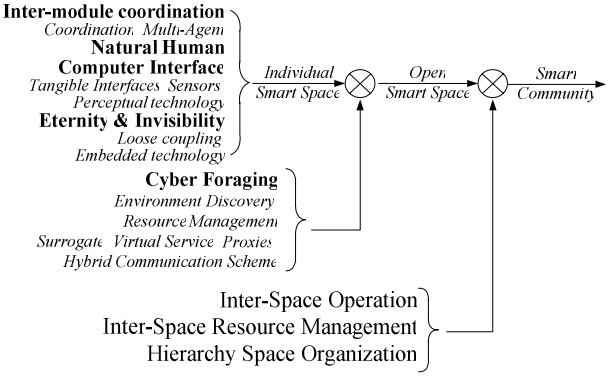

Fig. 1. The three successive phases of Smart Space

Individual Smart Space. In first phase, the research focuses on building a smart human-computer interactive space. It emphasizes the communication and the coordination mechanism among the software modules in a relatively close smart space. To support the coordination between modules, coordination models and multi-agent system have been studied. Also, lots of tangible UIs [10], such as sensors and awareness modules, have been applied to achieve friendly human computing interaction. Modules in Smart Space are loose-coupled in order to maintain system robust and embedded technologies are involved to remove the computing device from people sight. The Smart Classroom project is mainly in this phase.

Open Smart Space. In the second phase, the mobile and handheld devices become more and more popular in pervasive computing environment. These devices, roaming with users, can discover the existence of smart space environment and spontaneously take use of the resources and the services in the space to perform tasks of users in an enhanced fusion.

Smart Community. In the third phases, as researchers in [6] refers that it is almost impossible to establish an union pervasive computing environment all over the world in the near future, while great plenty of self-governed Smart Spaces exist by their own. Smart Community, which consists of multiple Smart Spaces, is considered as the research object of Smart Spaces. Inter-space operation and inter-space resource management mechanism among multiple Smart Spaces are needed to be studied on in this phase.

Note that the Open Smart Classroom mainly focuses on the second phase with primary work in the third phase. Besides studying cyber foraging, it also tries to establish well services invocation channels among inside and outside of Smart Space. Moreover, it tends to build the communication connection among Smart Spaces and does a primary study on inter-space resource management and communication.

There are several projects working on improving the experience of traditional classroom-based learning using Smart Space technologies. Active Class [11] is an application for encouraging in-class participation using personal wireless devices. The students give feedback of the class by their own wireless devices, improving the effect of traditional learning for both of teacher and students. However, Active Class lacks of supporting mobile devices to control and interact with the whole classroom, and has few natural human-computer interaction interfaces to enhance the experience of learning. eClass [1] in Georgia Tech is another project to study a general ubiquitous computing research theme, automated capture of live experiences for later access. Similar to the Smart Classroom project in Kyoto University [20], they both mainly study on capturing of the live experiences of the class for better understanding and further reviewing. But both of the two projects only work for single classroom and do not take into account live-class participation to remote students. iRoom in Stanford [2], explores new possibilities for people working together in technology-rich spaces, where has large displays, wireless or multimodal devices, and seamless mobile appliance integration. iRoom are used for discussion and learning, while it cannot allow remote students interaction either. Smart Classroom in Tsinghua University [17], similar to iRoom, well supports remote student interaction and communication, however, lacks of mobile devices communication mechanism without any pre-installed modules and is limited to utilize useful outside services. All these projects lack of supporting multiple classrooms working together, which is one of the important features that need to be emphasized in the future learning system.

Many software infrastructures for Smart Space exist with similar but a little different key features. Smart Platform [16] developed by Tsinghua University addresses the issue of performance and usability, which has three different communication schemes and loose-coupled multi-agent encapsulation architecture. However, Smart Platform has little implementation on the terms of services and multiple Smart Platforms communication. Similar to Smart Platform, iRos [2] by Stanford is meta-OS that ties devices together that each has their own low-level OS. As the extension of iRos, iCrafter [10] allows users of interactive workspaces to flexibly interact with the services in the workspace. Unfortunately, even with iCrafter, the software infrastructure does not consider the problem of multiple Smart Spaces communication. Hyperglue [8], which is a complement system of Metaglue [9] in MIT, involves the multiple Smart Spaces resource management. Meanwhile, both Hyperglue and Metaglue use Java RMI technology and their extended solution for direct coordination among different modules, which takes greater expenses because of the highly dynamic feature of Smart Space. Gaia [7] is a middle infrastructure with resource management and provides the user-oriented interfaces for such physical spaces populated with network-enabled computing resources. Gaia enables data and applications of users to be abstracted, that can be moved across and mapping to different the Smart Spaces. Gaia support services quite well, however, lacks of emphasizing on multiple Smart Spaces communications mechanism either.

3 Open Smart Platform

In this section, we are going to deeply introduce the details of its software infrastructure, Open Smart Platform.

3.1 Architecture

Single Smart Space. From single Smart Space view, the Open Smart Platform is described as Figure 2. Similar to Smart Platform, Open Smart Platform has a central DS, several container running on each of the host, each of which lots of agents running on. The reason why we inherit the multi-agent architecture of Smart Platform is because it has been well-developed and validated by several projects and also compatibility with previous work on Smart Platform concerns. The key improvement is that there are two system modules added: Web-Service-Wrapper-Agent (WSWA) and Smart-Platform-Agent-Webservice (SPAW).

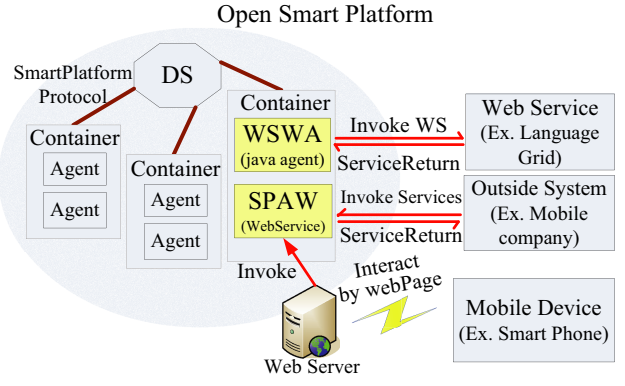

Fig. 2. Open Smart Platform architecture for single Smart Space

- WSWA is an agent, which invokes an outside web service based on the message received from other agents and returns the reply from the web service to the agents. Agents in Smart Platform can invoke outside web services by sending messages to this agent.
- SPAW is a web service deployed on Axis [21]. It receives messages from outside systems, transforms the messages to the protocol used in Smart Platform, creates a SPAW-agent to dispatch the message, and returns the reply from the agent to outside systems. Through this mechanism, outside systems can interact with agents in Smart Platform as web services. It also allows us to make and deploy workflows using agents in Smart Platform and web services, such as BPEL [13], has been involved, which makes the developer more easily customize their tasks. Moreover, as a web service, SPAW can be easily invoked by a web page server, where almost all current mobile devices can browse web pages and thus interact with modules inside of Smart Platform through SPAW.

In short, Open Smart Platform for single Smart Space is a multi-agent system with WSWA and SPAW as access point of communication between the inside and outside of Smart Space. From the inside view, communications are all based on Smart Platform Protocol, which is familiar with by previous Smart Platform developer. From the outside view, functions are all web services, which is the best for web service developer to build their tasks. Using WSWA and SPAW, we construct a communication

bridge between the Smart Space and outside systems, which opens Smart Platform to outside systems.

Smart Community. For Smart Community, where several Smart Spaces communicate and coordinate with each other, we establish the communication channel for them suitable for open network among them. Take two Smart Spaces for the simplest Smart Community as example, the architecture is shown in Figure 3.

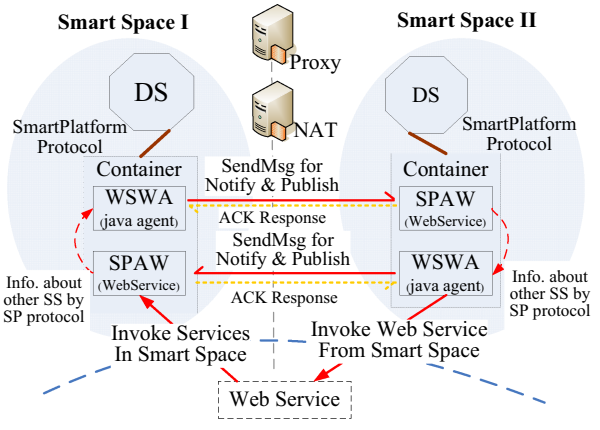

Fig. 3. Open Smart Platform architecture for two Smart Spaces

As mentioned above, WSWA and SPAW is the access point between inside the outside of Smart Space. Therefore, we take them for granted to exchange messages between Smart Spaces. Establishing the communication channel between every two access points is the ideal way for exchanging message, and using Web Service technology with HTTP protocol is the best way for the open network, where lots of routers, proxies, and NAT may exist along the message packet routing path.

In single Smart Space, agents publish messages to specific message group, and agents who have subscribed this message group will receive them. This Publish-Subscribe mechanism well supports the loose-coupled modules in Smart Space. And we believe it is also a good solution for message exchanging in Smart Community.

Therefore, we extend WSWA to be not only a delegation for agent in Smart Space to invoke outside web services, but also notify other Smart Spaces about message subscription and publication events. When SPAW receives one message of other Smart Spaces, it will first create a SPAW-Agent, by which publish the message content to the message group which is given in the message. So that all of the Smart Spaces can share their message group to each other, which makes the message exchanging just the same as what is in one Smart Space. It also alleviates the workload to update previous projects in single Smart Space to Smart Community environment.

Hence, the Open Smart Platform for Smart Community is still a multi-agent system which supports the Publish-Subscribe message exchanging method apparent to agents in each Smart Space.

3.2 New Features

Three new features of Open Smart Platform will be elaborated below:

– Extensibility for mobile devices.

Previous Smart Platform enables mobile devices roaming with users to connect into Smart Space by pre-installed modules (eContainer and eADK-based agent of Smart Platform), however, it lacks of convenience for the users, especially for those who first come into Smart Space to use their mobile devices. Open Smart Platform applies new mechanism named web-based-mobile-interface for mobile devices interaction in Smart Space. Open Smart Platform makes the required mobile interfaces, such as PPT upload or Turn-to-Next-Page, on web-based-mobile-interface as a website. Since almost all the mobile devices, such as Laptop, PDA, Smart Phone, or even normal cell phone have integrated web browser, the only thing that user need to do is to browse that website and click the corresponding link. The link is connected to SPAW, which will create a temporary SPAW-Agent to finish the whole task. If there is any reply information for that interface, for example, 'Check the schedule for Smart Classroom', the SPAW-Agent will return the result to SPAW and then got by the web browser of the mobile devices.

Note that new mechanism is not suitable for real-time streaming application (e.g. real-time multimedia streaming) because of the limitation of HTTP protocol new mechanism adopts. Therefore if the mobile users only use non-streaming function, such as controlling the PPT, he can use the web-based-mobile-interface to finish the task; otherwise, he can still utilize eContainer and eADK-based agent to help him to do that.

– Extensibility and scalability by services communication channel.

Thanks to WSWA and SPAW, invoking web services from outside and by outside systems (including other Smart Space systems) are possible, standard and easy. With WSWA delegation, it is unnecessary for each agent to deal with the problem of invoking web services, such as managing the life cycle of the web service stub. All is simple and easy by sending a web-service-request-message to WSWA and waiting for the result. Also, since all the services descriptions are shown on SPAW, it is very easy for the outside system to use services in Smart Space by simply invoking the corresponding services on SPAW. The services communication channel fills the gaps between the isolated services in Smart Space and outside services and systems, which makes the Smart Space more open.

Moreover, customization of tasks in Smart Space is easier. For example, the system should decide whether using machine translation or not according to the mother-tongue of users. As agents can easily create services in Open Smart Platform, and from the outside view, those services are all web services, therefore we are able to use mature workflow design tools to ease our customization work. We involve Active-BPEL [18] designer into our system, which really enhances the project developing efficiency by its visual interface and allows us to simulate our workflow to find bugs.

– Connection of multiple Smart Platforms in open network.

The most novel feature given by Open Smart Platform is enabling multiple Smart Platforms to connect with each other in open network. In the architecture, we place each Smart Space in equal hierarchy, which is primary work that just suitable for

small scale Smart Community. Open Smart Platform focuses on building the communication channel among multiple Smart Spaces, which gives each Smart Space a single message access point (WSWA & SPAW), and extends the previous successful Publish-Subscribe mechanism to Smart Community communication.

In previous Smart Platform, three communication schemes are presented that concern three aspects: size of transferred data, sensitive to data drop, sensitive to real time [15]. In Open Smart Platform, there are similar three communication schemes correspond to three different QoS requirements, which are suitable to multiple Smart Spaces communication. The message scheme has been extended for multiple Smart Spaces, while the stream scheme and bulk scheme keep the same as in previous Smart Platform. In Open Smart Platform, WSWA and SPAW help the agent in one Smart Space to send query message to another agent in another Smart Space and transfer the response message back. Then the two agents in two Smart Spaces build their connection by themselves, using the stream or bulk scheme interface to communicate with each other.

Using SPAW and WSWA for the single access is more convenient for message management and system safety consideration. It also simplifies the agents developing process that the programmer does not need to think about how to get through frustrating NAT, Proxy or Firewall in the open network. Additionally, as all messages between one Smart Space and the other are transferred through the link between two pairs of SPAW and WSWA, we can choose the best network link for them to get best efficiency for messages transfer between the two Smart Spaces.

Open Smart Platform provides the necessary basis for the connection of multiple Smart Spaces in open network, thus makes the application of multiple Smart Spaces, such as Open Smart Classrooms, possible and easy to build.

To sum up, Open Smart Platform successfully addresses the issues raised by developing pervasive computing. It supports multiple Smart Spaces connections, easy mobile device interaction and services communication channel between inside and outside of Smart Space. These new features provide a well software infrastructure basis for building Open Smart Classroom and other Smart Space and Smart Community related projects.

4 Open Smart Classroom

Open Smart Classroom is an extension of previous Smart Classroom project. Besides the features such as real time interactive virtual classroom and blended learning mode, Open Smart Classroom mainly focuses on the following two issues, which make it an open classroom compared to other related works.

– Enabling multiple classrooms to connect with each other in the open network.

Involving multiple classrooms to have class together, especially for classrooms in different countries, has great significance to intercultural and intercontinental learning. Open Smart Classroom tries to combine several Smart Classrooms together to give novel experience for the teachers and students in the class. Also, considering the differences of classrooms, such as the different using language, the different infrastructures and devices, necessary transformation is needed in order to gain better connection effect. In the recent Open Smart Classroom, we primarily take different

languages into account by involving Language Grid [14][16] translation engine for better understanding.

– Open the classroom interface and makes the classroom open to outside services.

Open concept is also for single Smart Classroom. The ease of using mobile device in the classroom to communicate and interact shows the open of the classroom. Moreover, the classroom easily taking use of the abundant resources, such as Language Grid translation service, presents the powerful extensibility of the classroom, which thus also embodies the open feature.

We build two scenarios to validate the Open Smart Classroom system, and also to present the open feature of our system.

Scenario I. Professor Shi enters smart classroom with a PPT, which is in Chinese, in her smart phone. She wants to give a presentation of that. Unfortunately, there are some students in smart classroom cannot understand Chinese but only English. The professor uploads her PPT file through the smart-classroom-ppt-support-website (SCPSW) by the web browser on smart phone. When the file is uploaded successfully, the website redirects to a link that invoking the workflow of this scenario: the PPT file is translated from Chinese to English automatically using Language grid web service of Kyoto university, then the translated version is shared to another machine which has another projector to show on. After that, the two versions of PPT will be started and synchronized on two projectors at the same time. As the class goes on, professor Shi uses her smart phone to control the presentation, such as turn to next page, by clicking the link given on the SCPSW.

Scenario II. Two Smart Classrooms are deployed in Tsinghua Univ. and Kyoto Univ. to have class together. Yue is giving a presentation in Tsinghua Univ, speaking English with an English PPT. The live video and PPT are shown in both of the two classrooms. And also, the translated PPTs, which are in Chinese and Japanese, show in Kyoto and Tsinghua respectively. However, Miyata, in Kyoto Univ. has some questions about this presentation. Avoiding interrupting the presentation, he raises his question in Japanese using Multi-language Chat Agent. Weijun, in China, who sees the question that has been translated in Chinese, answers his question in Chinese.

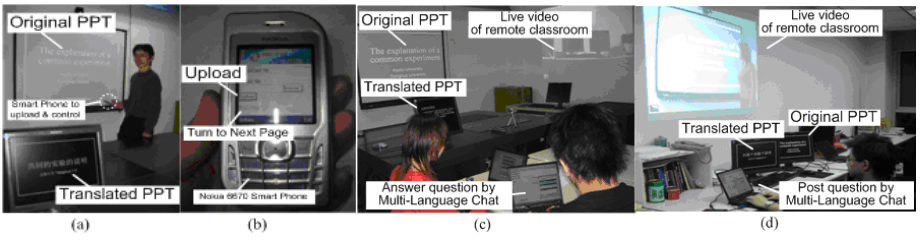

Fig. 4. Snapshots of Scenario. (a) Teacher using smart phone to control the PPT slideshow (b) The snapshot of PPT upload website on smart phone (c) The demo classroom in Tsinghua University (d) The demo classroom in Kyoto University.

The two scenarios of Open Smart Classroom were developed and tested successfully in Kyoto and Tsinghua Univ. from September in 2006 to February in 2007, which also validated our Open Smart Platform (see Figure 4). Most students reported

that it was very interesting and useful to see the original and translated PPT at the same time, which help them a lot in understanding. The teacher also reported that to upload and control the PPT by Smart phone without any prior configuration is excellent and convenient, except the uploading process is a little delay, but it is tolerable. The little delay is because the speed of uploading PPT is limited by GPRS connection, which will surely be improved by 3G or 802.11n standard deployed pervasively in the near future.

We also evaluate the performance of message transfer between two Smart Spaces. In Scenario II the PPT file is transferred from Tsinghua University to Kyoto University. And students in two Smart Classrooms use Multi-language Chat Agent to send questions and answers to each other. In the experiment the message exchanging speed is well enough according to the students' comments.

5 Conclusion and Future Work

New requirements raised by the development of pervasive computing have been pointed out, and to meet them, we make Open Smart Classroom, which is based on Open Smart Platform to enable the teacher and students to have intercontinental and intercultural class with better mobile device cooperation experience. Open Smart Classroom envisions the future learning system, where classrooms are connecting and collaborating with each other in open network while the students and teachers with different cultural background in different countries are having class together.

Open Smart Platform, as an upgrade of Smart Platform, is still a multi-agent system integrated with several extensions, serving as the generic software infrastructure for Smart Space. It enables better support in three aspects: 1) Successful connection multiple Smart Platforms together in open network; 2) Service invocation channel between inside of Smart Spaces and outside systems; 3) Easy interaction for mobile device roaming with users.

Currently we place each Smart Space in equal hierarchy. However, as the emergence of more and more Smart Spaces, it is necessary to involve multi-layer hierarchy for optimization and better management.

For Open Smart Classroom, we are now developing a new project to study on the effect that people use this environment for intercultural learning, where participants in different Smart Spaces can listen to the presentation in formal communication language (e.g. English), and communicate with each other in their native language to understand the new word or new concepts which are not well explained in the presentation. At the same time, we also consider to build more web services and interesting applications to let the students in Tsinghua and Kyoto University to carry on novel experiment in the near future.

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