

A Kind of Smart Space for Remote Real-Time Interactive Learning Based on Pervasive Computing Mode

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Abstract. As a kind of Smart Space, real-time interactive virtual classroom is an important type of remote learning. However, available systems nowadays are not adaptable large-scale user access and cannot accommodate heterogeneous computing devices and different networks access either. Furthermore, these systems are almost desktop-based. The Smart Classroom Project based on pervasive computing mode whose focus is on supporting software infra-structure, context-aware computing, implicit human-computer interaction, interconnection of computing device, etc. tackles the difficulties through these technologies: A hybrid application-layer Multicast protocol, a dedicated software called SameView, an augmented classroom called Smart Classroom, many kinds of learning patterns' computing technology, interconnection learning via wireless and wired communication protocol technology. So the teacher can instruct the remote students just like face-to-face teaching in a conventional classroom. All these developed technologies has been successfully integrated and demonstrated in a prototype system. The efficiency of our researches has been tested by the demo.

1 Introduction

The advances of personal computers and the Internet have laid the groundwork for the revolution and the rapidly emerging era of intelligent, networked devices. This world of connected devices offers new levels of customer service and computing capability. Many new technologies introduce support for embedded mobile or fixed IP communications in the network, which will increase device-site capacity. Its embedded nature also means that devices can be “always on the network”, but only pay for services when sending or receiving data. These changes are beginning to allow subscribers access to the “invisible device applications”. The migration paths from foolish-device and smart-device to networking-device are clearly mapped out in many cases. However, as respective countries roll out their broadband networks and services, it will be unlikely that the devices will offer the initial coverage that their existing smart-device provide. Therefore, no matter what you do and no matter what you call it – pervasive /ubiquitous computing, e-business, e-learning, or e-services, we are entering

a new age of computing, namely, the era of pervasive computing era, which is studied only recently computing mode.

As we know, desktop and laptop have been the center of human-computer interaction since the late of last century. In this mode, people often feel that the cumbersome lifeless box is only approachable through complex jargon that has nothing to do with the tasks for which they actually use computers. Too much of their attention is distracted from the real job to the box. Deeper contemplation on valuable matured technologies tells us: the most profound technologies are those that disappear, which means they weave themselves into the fabric of everyday life until they are indistinguishable from it. We use them everyday, everywhere even without notice of them [Weiser 1991]. This inspiring view of prospect has been accepted and spread so fast and widely that in a short time of a few years, many ambitious projects have been proposed and carried on to welcome the advent of pervasive computing. There are a bunch of branch research fields under the banner of it, such as Mobile Computing, Wearable Computing, Nomadic Computing and also Intelligent Space, etc. The focus of this paper, Smart Classroom, belongs to the field of Intelligent Space.

It is obvious that the need for wider access to education, support for life long learning, and more part-time and remote real-time interactive learning (RRTIL). The Web/Internet provides relatively easy ways to publish hyper-linked multimedia content, and reach a wide audience. Yet, we find that most of the courseware are simply shifted from textbook to HTML files. Audience read from the book in the past and now read from the screen. However, in most cases the teacher's live instructing is very important for catching the attention and interest of the students. That's why Real-time Interactive Smart Space (RTISS), such as Virtual Classroom (VC), plays an important role of consequence in Distance Learning, where teachers and students located in different places take part in the class synchronously through certain multimedia communication system and can have real-time and media-rich interactions. However, to provide this type of Distance Learning in large scale still remains some barriers [Shi 2002]: It is not enough that adequate technologies to cope with large-scale access and adequate technologies to accommodate students with different network and device conditions in one session, such as wireless communication, mobile computing, nomadic computing, etc.

As a test bed and a prototype of pervasive computing mode, the Smart Space Project ["863" Plan of China] at our institute is a long-term project aiming at providing adequate technologies to overcome the above-mentioned difficulties in current practice of RRTIL and building an integrated system for the next generation real-time interactive distance learning in China. Currently we have made progresses in the following aspects: A software infrastructure based on pervasive computing mode, a dedicated software interface for RTISS called SameView and a *prototype system* have been developed.

The rest of the paper will be organized as following: First, discuss the focus problems of Pervasive Computing Mode. Then suggest the main scenario of smart space, later introduce a prototype system of our Smart Space Project – Smart Classroom. Finally give a conclusion.

2 The Focus of Pervasive Computing Mode

In researches of smart/intelligent space/environment, there are several relevant and challenging problems which is the focus problems of pervasive computing mode need to be solved, such as the Pervasive Computing software infrastructure, Context-aware Computing, Implicit Human-Computer Interaction, the inter-connection of computing devices on many different scales based on different layers' network protocol, the handling of various mobility problems caused by user's movement, application substrates, user interfaces issues etc. Although many projects have been conducted in the name of smart/intelligent space/environment, they have different emphases. Some focus on the integration of different sensing modalities, some aim at the adaptability of smart/intelligent space/environment to user's preference [Shi 2002], we developed special interest in exploring the impact of pervasive/ubiquitous computing to education. This leads to the prototype project of Smart Classroom.

2.1 The Supporting Software Infrastructure

In our point of view, there are several main different point of the supporting software infrastructure between the pervasive computing mode and traditional mode: It must manage the virtual space of computing network and physical space around the field at the same time. It must supply all kinds of functions and services, which are based on the space of daily life but not based on a special environment, the composing and structure of the software infrastructure are often changing. It must deal with the diversification of device, especially, including many mobile devices and wireless devices, that is to say, It must be adaptive to its object. It must be extendable, open and loose. etc.

As our opinion, the function and service of supporting software infrastructure should include as following:

(1) *Spontaneous discovery method of resource and services.* When a new device is brought into a space or new module is used in the old device, the infrastructure can know how to spontaneously discover them and what is wanted to be interactive.

(2) *Adaptive interactive mechanism.* Because the resources of device are not same in a system, they may be embedded device, wearable computing device, basic components, etc. their computing capability, memory capability, interactive mode are too different. When the device is mobile or nomadic in the different environment, the interconnection problem is existed. the infrastructure can transform or translate the contents.

(3) *Coordination mechanism among modules.* As a distributed mode, the infrastructure can coordinate the relationship of association, communication, collaboration of modules, so Coordination mechanism among modules is more important to the whole function and services.

(4) *Tolerance mechanism when the resource is not enough.* Because of the complexity, such as the scenario of movement in the different space between wireless communication device and fixed communication device, the scenario of spontaneous

cooperation among different modules, the error rate or loss rate is high, but the fault is temporary, the infrastructure can tolerate these cases and not stop, quit, or break down.

(5) *Privacy and security ensuring mechanism when spontaneous cooperation.* the infrastructure can not let the important information be modified, obtained by hostility, known by no authorization.

2.2 Context-Aware Computing

Although context information has been used in PC's computing mode, the content of it is fixed and set by manual and in pervasive computing, the content is changed with the task or event. Owing to the field/local of work environment, the complexity of its background is obvious, the dynamic change of context stands out. During the interaction, the importance of context is that : The same input, different context may be different annotation. The efficiency of interaction can be improved, so it distracts the user's attention within the less limit, which is the one of targets of pervasive computing. The physical interface under the pervasive computing mode is not private but shared by many users. In order to realize the individuation of interface and service, the context information is necessary.

The requirement to context-aware runs through each layer from lower hardware to upper application & interaction. As our opinion, the main technology of context-aware computing should include as following:

(1) *Obtaining of context information.* Context information is in different layer, both lower and upper, some can be obtained from the sensors directly, such as temperature, face character, some may be reasoned indirectly, such as normal state, abnormal state.

(2) *Modeling of context information.* In order to exchange the context information among different modules, system, environment, the model of context must be set up, including the expression method of context information, reasoning of uncertainty. The expression method must be common, which can permit the same context information be understood by different process module or agent. Owing to the noise and uncertainty of sensing data, the probability and statistic character of context information, the reasoning capability should be used frequently.

(3) *Management of context information.* How to query and store the context-aware information, how to schedule the context information, come a conclusion and supply the service actively, the management capability of computing platform is very important.

2.3 Implicit Human-Computer Interaction

Implicit human-computer interaction is distributed and attentive / proactive in fact. The former is that interactive interface of computing device is distributed in the 3D space, not in the front of a certain computer. The latter is that in this computing environment, the computer is not waiting for the controlling command passively, but supplying the individuation service passively in time according to what has been detected and recognized about the state of physical, emotion and cognition of the user and

context-aware information. This is to say, the function and service of it should include as following:

(1) *Detection and recognition of user's physical state.* User's physical state includes user's biological character identification, position, gesture, vision angle, etc.

(2) *Detection and comprehension of events.* By the sensing data and context-aware information, the action of the user and the relative event are detected and recognized, so the intention of the user is comprehended.

(3) *Detection and comprehension of user's emotion.* By the sensing data of audio, voice, etc, the emotion of the user is comprehended.

(4) *Fusion of multi-modal data.* Multiple sensors has been used, the sensing channel is multiple level, so the data is multi-modal, only by fusion, human-computer interaction may be done. This is the key technology.

(5) *Learning of user's action rule.* In order to supply individuation service, each user's custom and taste may be known by learning from the interactive data and recollection of user's calendar.

2.4 The Interconnection of Computing Device

The data exchange/switching is needed between different computing devices by different network, such as wireless infrastructure-based communication, multi-hop ad-hoc networks, dynamic topology without any infrastructure-based communication, Internet-based networks. Different computing devices are interconnected using IEEE 802.11x and Bluetooth technology, mobile devices may use GSM communication technology, also use GPRS, UMTS, DECT, etc. instead. Especially, although suitable routing protocols enable communication in multi-top ad-hoc networks, such as DSR, TORA, AODV, communication paths between sender and receiver can break when the network is topology is partitioned due to the movements of the nodes. Large-scale interactive applications have demanding requirements on underlying transport protocols for efficient dissemination of real-time multimedia data over heterogeneous networks [Kuo 1998]. Existing reliable multicast protocols failed to meet these requirements due to following reasons: (a) most protocols presume the existence of multicast fully-enabled network infrastructure, which is usually not the case for current Internet; (b) protocols that support multiple concurrent data sources only have limited scalability; (c) few of them have implemented end-to-end TCP-friendly congestion control policy.

Consider the following situation in a scenario which supports pervasive computing: In order to conserve energy, laptop A in the ad-hoc network initially communicates with laptop B using Bluetooth via the PDA. If B becomes unreachable, for example, when A moves out of the coverage of the Bluetooth network or when the PDA is switched off, communication is no longer possible. A's TCP connections will time out, even if B is still reachable using the IEEE 802.11x link. The reason is that a TCP connection is uniquely identified by a quadruple (IP address A, port A, IP address B, port B) and switching to another network interface results in a new source IP address related with this interface. However, it is also harmful to change the bindings of IP addressed to a networking device due to three reasons:

- (1) *The mobile node becomes unreachable as the new address bound to the network interface might be topologically incorrect.*
- (2) *The process of binding, unbinding, and the internal routing table is not very efficient.*
- (3) *Caching of ARP information is not possible as the matching between IP address and MAC address changes after the modification.*

So a seamless and transparent switching mechanism between different networking interfaces is needed. Several service location protocols have been developed in the last few years. Among the most famous are Jini, UPnP, Bluetooth SDP, Salutation and SLP. Most service location protocols may be used in ad-hoc networks for pervasive computing mode. Some protocols, such as Jini, UPnP, even provide service access in addition to service discovery, in case of Jini even without the need of pre-configured drivers for a service. For ad-hoc network it is also important that a central service manager is not required because in a dynamic environment a centralized entity is always a single point of failure. So service location protocols that implement distributed service managers or enabling direct discovery of services at a particular device should be preferred in ad-hoc networks.

Seamless switching between different networks for different computing devices is a basic feature for improving the quality of a perceived service under the pervasive computing mode. However, the heterogeneity also implies that the services are also distributed over the accessible ad-hoc networks. Due to device mobility, the services need to be regularly discovered and their availability is not ensured as mobile devices can be frequently switched off and on by their users. For example, In the scenario described above, the laptop A has a connection to the Internet, using a gateway from ISP2. This gateway can be reached by means of IP routing via laptop B. If B is switched off A's connection to the internet terminates. In this case, the service location protocol running on A has to discover an alternative proxy providing Internet access service in the heterogeneous ad-hoc network. In this case a proxy form ISP will be used which can be reached via the other route. Afterwards, the network settings of A need to be reconfigured and the application must be restarted as the source address might have changed.

3 The Scenario of Smart Space on Pervasive Computing Mode

Fig. 1 depicts an example of the main scenario of Smart Space based on pervasive computing mode, such as Smart Remote Classroom, which is integrated into an overall scenario to enable a revolutionary real-time interactive distance learning practice. In this scenario, we have shown the communication mode by wireless network and INTERNET NETWORK. A reporter, such as teacher gives a report/class with natural ways in this Smart Space where could also exist local audiences/students, while the remote audiences/students connected by Internet access the report/class with SameView clients. The remote audiences/students can see the presented report/class materials, the annotations made during the report/lecture, the live audio/video in the

Smart Space and also can take the initiative to interact with the reporter/teacher, just like attending the space/classroom locally. Furthermore, the process of the report/lecture will be recorded as a multimedia courseware for playback after report/class. In addition, If several audiences/students have mobile computing devices, who can join in the report/class by wireless network, they may learn freely or discuss with other audiences/students or ask the reporter/teacher for questions, and so on.

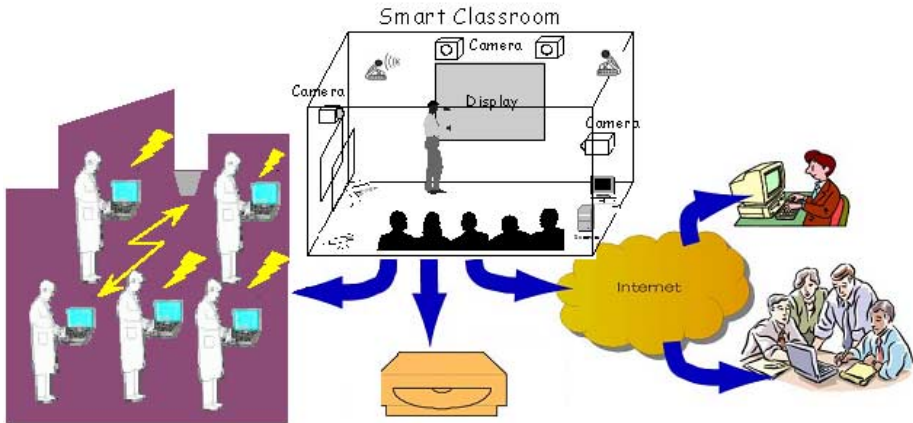


Fig. 1. The main scenario of Smart Space

In the smart environment of pervasive/ubiquitous computing, because of many interconnected computing devices and wide area network environment, collaborations of multi-user and multi-device can be the most important. And the support for collaboration is becoming a requisite of a smart space. The collaborative work support of a Smart Space can be categorized into two classes. One is the collaboration of multiple attendants within the Smart Space holding various computing devices, such as pen-based devices, hand-held devices and wearable computer etc. The other is the collaboration of remote participants and local attendants. The demand for collaboration support is so obvious that many commonly observed tasks in a space, need the collaboration of multiple objects.

So the Smart Space is essentially a distributed parallel computing environment, in which many distributed software/hardware modules collaborate to accomplish specific jobs. Software infrastructure is the enabling technology to provide facilities for software components' collaboration. There are some candidate solutions to software infrastructure, such as Distributed Component-Oriented Model, like EJB, CORBA, DCOM, etc, and Multi-Agent Systems (MAS). In the context of Intelligent Environment, Multi-Agent System is more competent than Distributed Component-Oriented Model due to the following reasons: higher encapsulation level, faster evolution from design to implementation, easier development and debugging, and most importantly, more accordant to the need of dynamic reconfiguration and loose-coupling. The network of distributed software modules is conceptualized as a dynamic community of agents, where multiple agents, such as Facilitator agent, Facial-voice identification

agent, motion-tracking agent, speech recognition agent, Virtual Mouse agent, etc. contribute services to the community.

4 A Prototype System of Our Smart Space Project

Smart Classroom, as a prototype system of our smart space project, is inspired by the research of pervasive computing mode. Smart Spaces are work environments with embedded computers, information appliances, and multi-modal sensors allowing people to perform tasks efficiently by offering unprecedented levels of access to information and assistance from computers [Smart Space]. Smart Classroom is just such a Smart Space deployed in a classroom [Xie 2001]. We augment an ordinary classroom with wall-sized displays, sensors, cameras and the associated computation and perception modules so as to allow the teacher in it access the SameView system transparently, rather than appeal to a desktop computer. By Smart Classroom, we actually extend the user interface of the SameView for teacher from a desktop computer into the 3-D space of the classroom.

The room setting is illustrated in reference [Xie 2001]. The teaching area of the classroom are augmented with two facilities: Mediaboard and Studentboard. Mediaboard is a physical embodiment of the shared mediaboard of the SameView software in the teacher's side, which is essentially a large touch-sensitive screen. Teachers can display prepared slides in this board and make or wipe scribbles on the slides with provided pens and erasers. Studentboard is a window to remote students, on which the image of remote students with presenter roles will be displayed and the video and audio of the remote student who has floor will be played here too. The student area of the classroom is just the same as any ordinary classroom, which can be occupied by local students. Around the classroom, there are near a half-dozen cameras, each with different usage. For example, some are used to recognize the action of the teacher and some are used to broadcast the live video of the classroom to the remote students. In addition, the teacher wears a wireless microphone to capture his speech. In Smart Classroom, the teacher no longer need to remain stationary in front of a desktop computer and to complete most of common tasks happened in a class, the teacher do not need to use keyboard and mouse. The natural teaching experience includes that Pen-based UI, Laser Pointer Tracking, Virtual Assistant, Biometric Character Based Login Process, Smart Cameraman and so on [Shi 2002].

4.1 The Software Infrastructure for Remote Real-Time Interactive Learning

The Smart Classrooms, just like many other similar smart space/Intelligent Environment setups, will assemble a good number of hardware and software modules such as projectors, cameras, sensors, face recognition module, speech recognition module and eye-gaze recognition module. It is unimaginable to install all these components in one computer due to the limited computation power and terrible maintenance requirements. Thus, a distributed computing structure is required to implement an Intelligent

Environment. We have currently completed a demo of the Smart Classroom (as Fig. 2). In order to an agent to communicate with each other, it should have a reference to the other peer. In order to make the system more loosely coupled and flexible, the reference binding should be created by some high-level mechanism. A usual implementation is binding by capability. That is to say, on startup, each agent should register its capabilities to some central registry, and when an agent needs some service, it could ask for it by describe the needed capabilities. However, the true challenge here is how to set up a framework for the description of the capabilities, which could enable a new agents to find out the exact semantic meaning of the capabilities advertised by other agents.

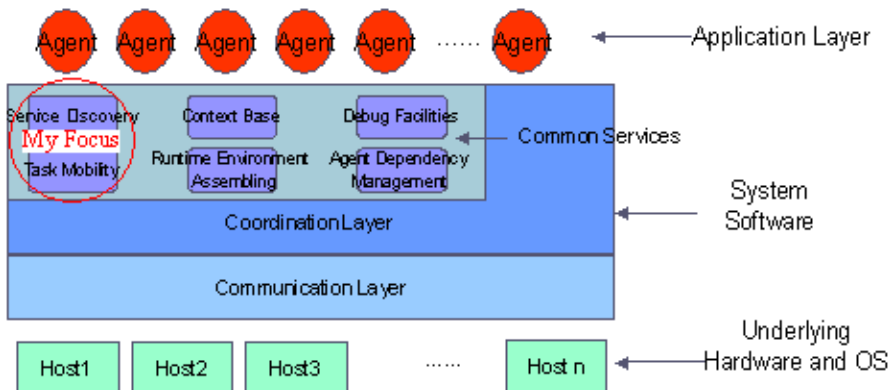


Fig. 2. A kind of software infrastructure for remote real-time interactive learning

The prototype/Demo system is composed of the following key components:

- *The multi-agent software platform.* We adopted a public available multi-agent system, OAA (Open Agent Architecture), as the software platform for the Smart Classroom. It was developed by SRI and has been used by many research groups. We fixed some errors of the implementation provided by SRI to make it more robust. All the software modules in the Smart Classroom are implemented as the agents in the OAA, and using the capability provided by it to communicate and cooperate with each other.

- *Multiple agents' realization.* The hand-tracking agent, which could track the 3D movement parameters of the teacher's hand using a skin color consistency based algorithm. It could also recognize some simple actions of the teacher's palm such as open, close and push. The same recognition engine had been successfully used in a project in Intel China Research Center (ICRC), which we have taken part in. The multi-modal unification agent, which is based on the work in the project of ICRC mentioned above, under a collaboration agreement. The approach is essentially based on the one used in Quickset as mentioned above. The speech recognition agent, which is developed with a simplified Chinese version of ViaVoice SDK from IBM. We carefully designed is developed with a simplified Chinese version of ViaVoice SDK from IBM. We carefully designed the interface to make any agents who need the SR capa-

bility could dynamically add or delete the recognizable phrases together with the associated action (an OAA resolve request indeed) when recognized. Thus the vocabulary in the SR agent is always kept to a minimum size according to the context of the time. It is very important to improve the recognition rate and accuracy. Some others have been finished except the service discovery agent and task mobility agent, which are ongoing research.etc.

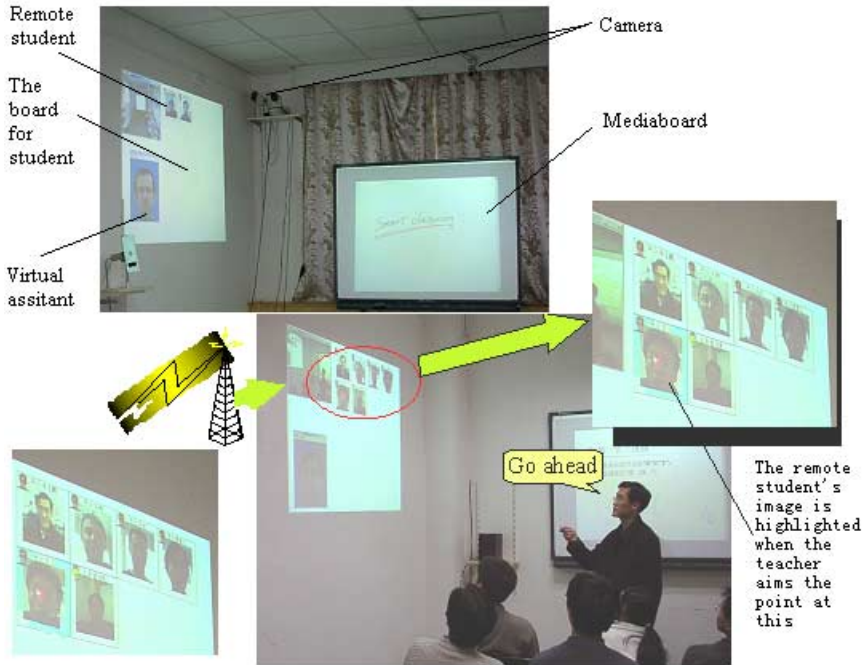


Fig. 3. A snapshot point of the SameView client

4.2 A Kind of Software for Remote Real-Time Interactive Learning: SameView

In order to support the remote real-time interactive learning, SameView is developed based on the proposed TORM and AMTM platform. Fig. 3 is a snapshot point of a SameView client. SameView provides a set of interaction channels for the teacher and local/remote students to efficiently achieve the goal of teach and learning [Smart Space]: shared Mediaboard which is a shared whiteboard capable of displaying multimedia contents, Live Audio/Video and Mutual Chat.

In the Smart Space, such as the Smart Classroom, real-time lecturing is a typical large-scale interactive application, where there may be hundreds or thousands remote students taking part in a virtual class. Reliable multicast is a useful network service but is also challenged research issue for the heterogeneity and the lack of full support of IP multicast in today's Internet infrastructure. Instead of following the traditional end-to-end model for reliable multicast, our research group developed a Totally Ordered

Reliable Multicast (TORM) protocol taking a hybrid approach that exploits both mobile/fixed IP Unicast and IP Multicast for data delivery. And during data forwarding, the Adaptive Multimedia Transport Model (AMTM) proposed is applied to dynamically trans-code the multimedia data for users with different devices and network capabilities.

5 Conclusions

Based on Pervasive Computing Mode, we have developed a set of key technologies for remote real-time interactive learning and make a new model of remote real-time interactive learning with following characteristics possible: (a) Able to accept large-scale user access the virtual classroom simultaneously with different network and device conditions. (b) The class can be recorded and turned into an ideal courseware for E-learning. (c) Support many kinds of learning patterns, such as mobile computing devices, wireless communication network environment. (c) Set up a channel of inter-connection learning via uniformed communication protocol.

Of course, our project is not completed totally, such as service discovery, task mobility, so our work is continuously ongoing. Although we have made concrete achievements on each part of the project and the integrated system has been successfully demonstrated with controlled.

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