Multi-agent system for User-oriented Healthcare Support

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Abstract - In this paper we propose an advanced healthcare support system in ubiquitous computing environment. By utilizing knowledge about healthcare and various information including vital sign, physical location, and video data of a user under observation from real space, the system provides useful information regarding health condition effectively and in user-oriented manner. In this paper, we describe a user-oriented healthcare support system based on concept of symbiotic computing, focusing on design and implementation of the system with multi-agent system.

Keywords: Healthcare support system, Ubiquitous computing, Multi-agent system, Context-aware service, Multimedia communication

1 INTRODUCTION

With the increase of people with lifestyle-related diseases such as obesity, hypertension, diabetes, and hyperlipidemia, health maintenance to prevent these diseases has been an issue of social concern. Information technologies are expected to give practical solutions to this issue, and some research groups have been investigating the solutions from engineering viewpoints [1]–[7]. In this context, ubiquitous computing technologies are promising, because they contribute to expand the scope of system support to users' daily lives. Hand-held terminals, wearable vital sensors, wireless communications, etc. are playing important roles in this application domain [8]–[18].

However, these existing systems are designed by using some specific vital sensors and electronic devices, therefore these systems are limited in ability of healthcare support. In order to provide useful information for healthcare of an object person, not only to him/herself but also to related people of the person, the system should acquire variety of information, knowledge, data, etc. from real space and store/manage them in a methodical manner. This means that we have to treat a new dimension of design and construction of large-scale systems that can cope with many kinds and amount of information on unstable processing environment of ubiquitous computing.

We have been investigating an advanced healthcare support system in ubiquitous computing environment. By utilizing knowledge about healthcare and various kinds of information obtained from real space, the system provides useful information regarding health condition effectively and in user-oriented manner. In this paper, we describe the concept and design of user-oriented healthcare support system based on multi-agent. The grand design of our healthcare system is based on symbiotic computing [19]–[21] that is a concept of post-ubiquitous computing according to co-existing of real-space and digital-space. Especially, this paper focus on the concept, design, and implementation of several function of our system with multi-agent technology that matches to realize this kind of large-scale and complex systems by employing such properties as autonomy, cooperativeness, and adaptability of agents. We also show the effectiveness of our prototype system with results of initial experiments.

The remainder of the paper is organized as follows. Section 2 describes related studies. The concept and an agent-based framework for healthcare support system are described in Section 3, and designs and implementation are illustrated in Section 4. We describe experiments and evaluation in Section 5. Finally, we conclude this paper in Section 6.

2 RELATED WORKS AND PROBLEMS

2.1 Related Works

There have been many attempts to assist healthcare support based on information technologies. In this section, we present related works about healthcare support systems, and summarize their problems.

Administrative organizations provide various kinds of information about healthcare on the Web [1], [2]. Several companies have developed a medical device and provide a healthcare service utilizing the device [3].

Some research groups developed support systems which recognize health condition of a user by monitoring user's vital signs using compact sensors, hand-held PCs, and wireless network in ubiquitous computing environment [8]–[13]. There exists the system which can infer user's behavior, activity, and emergency situation according to the vital signs and location information of the user's by using wearable sensors. In [14], Chang et al. studied methods that automatically recognize what type of exercise the user is doing and how many repetitions he/she has done so far. They incorporated a three-axis accelerometer into a workout glove to track hand movements and put another accelerometer on the user's waist to track body posture.

A project [5] was promoted to develop a prototype of next generation network system which can provide high quality health service with sufficient security and protection of user's privacy. Under the project, a health advice derivation system has been developed [6]. This system can derive health advice according to the user's condition and knowledge about health.

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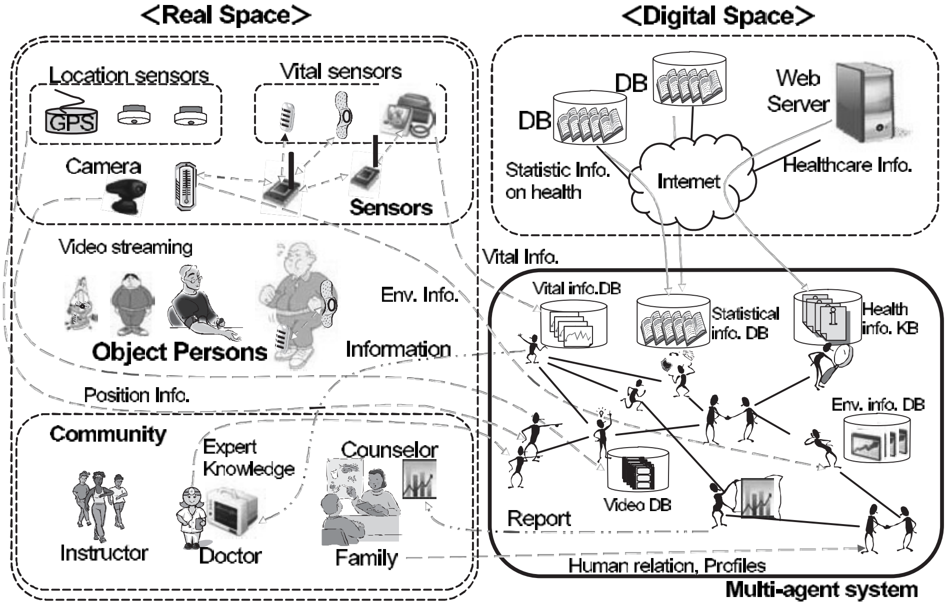

Figure 1: Concept of user-oriented healthcare support system based on multi-agent

2.2 Problems

¿From discussion on previous works in Section 2.1, we point out technical problems in existing healthcare support system as follows.

- **Effective acquisition of various and amount of information for multiple object persons (P1):** There are studies determining the health condition based on vital sign by specific sensing devices in real-time. But the information has limitations for obtaining an accurate estimation of the health condition because the information is obtained by the vital sign limited piece of information on only a certain individual. It would be possible to perceive the health conditions of multiple object persons with greater accuracy using physical location of the persons, environmental information such as ambient temperature and room brightness, and video information of the persons, as well as the vital sign. However, it is difficult to acquire all the information in real space for multiple object persons because of the limitation of computational resources and network resources in the ubiquitous computing environment. Consequently, we need to consider the effective way of information acquisition from real space.

- **Effective inference mechanism using various kinds of information of real space (P2):** After acquisition of various kinds of information from real space, effective information and real-time service provisioning using the information would be a challenge. The data and information including vital sign, location information, environmental information, multimedia data, specialized knowledge, etc. contain significant diverse aspects in both quantitative and qualitative. By using existing inference mechanism, we cannot cope with these kinds of information and knowledge in real-time. Therefore, we need an effective inference mechanism for actively-provisioning in real-time.

- **Infrastructure of system construction (P3):** In the related works, specialized systems in each area of healthcare have been developed in an ad-hoc manner. Thus, we do not have an infrastructure of system construction to facilitate implementation of systems for various healthcare areas. The infrastructure needs system extendibility to introduce new sensor device, wireless network technology, diagnosis algorithm for analyzing condition of health, DB system etc. in easy ways. In order to enhance extendibility and flexibility of system implementation, we require consideration of common software infrastructure containing platform and components dedicated to healthcare support.

3 CONCEPT OF USER-ORIENTED HEALTHCARE SUPPORT SYSTEM BASED ON MULTI-AGENT

3.1 Overview of User-oriented Healthcare Support System

Figure 1 shows the concept of our proposed system. We propose a methodology of construction of user-oriented healthcare support system based on multi-agent to solve the problems mentioned above in Section 2.2.

This system assists the object persons and community members related healthcare support services. The community members are related to the object person such as family member, sports gym instructor, doctor, etc. to circulate healthcare related information and knowledge effectively. The system collects information on the object person such as profiles, preferences, history of exercise, medical records, human relation, etc. from the healthcare community members. The system actively observes the current status of the object person and his/her surrounding environment such as physical location, temperature, body warmth, HR, BP, etc. by using various types of sensors. These are the information flows from real space to this system.

On the other hands, the system accesses to the Web site and databases (DBs) via the network to fetch useful information on healthcare. These are the information flows from digital space to this system. The information, data, and knowledge are accumulated in the system in adequate forms. If needed, they are used to analyze the situation of the object person in detail. The information is sometimes provided to the person and the community members by proper timing and forms, considering privacy concerns and resource limitations of the devices.

¿From the viewpoint of the symbiosis between real-space and digital-space, this support system is an accelerator of information circulation in order to promote the healthcare tasks. However, huge amount and functional diversity of the information, involving the privacy concerns, make it very difficult to accomplish.

3.2 Applying Multi-agent Technology

A multi-agent system is a distributed autonomous coordination system. Various types of system component are wrapped (this wrapping is called "agentification"), and then it gets possible to work as an agent. The multiple agents can dynamically configure organization to process some intended tasks.

Consider the situation where some vital data or location information is acquired by a sensor device, transmitted via the network and stored in a DB. Each agent individually resides in various sensor devices. The agent monitors and controls corresponding hardware. Also the DB which stores acquired data is made to work as agent. Quality of information and frequency of the acquired data should be controlled depending on network status, operational condition of the sensor device, and load of the DB. The proposed system can effectively control the data flows based on the situation and health condition of the object person by cooperation among sensor agent, DB agent, and network agent. This will be a solution to (P1).

The accumulated information is basically in the form of raw data. It should be converted into more user-friendly forms such as tables and graphs. Some data can be used to analyze the situation of the object person to create knowledge or advice with high-level expression. These analytical results can be used by agents' organizational behaviors. For example, when the object person is in bad health condition, the sensor agent that observes the vital data of the person would try to acquire more detailed information in shorter time intervals. To realize these kinds of intelligent analysis, each agent has basic inference mechanism based on the rule-base system. For more special knowledge processing, some kinds of powerful tools, such as ontology-base, data mining algorithms, software for statistics, etc. are needed to cooperate with each other. Therefore we need to wrap each tool as an autonomous agent. The various health conditions are elicited in an efficient and effective by assistance based on collaboration and cooperation with the workable agents. This would be a solution to (P2).

In addition, agentification of various devices, database, knowledge, algorithm for analysis, software components, etc. makes reusable module, and agents can dynamically configure a complex system. It is possible to build a new component into the existing system at the lowest possible cost when the component is introduced. Thus the infrastructure of system construction based on multi-agent system will realize reduction of system development cost and advancement of the system. This is another important aspect for ubiquitous applications whose technologies are proceeding at a rapid rate daily. This will resolve the (P3).

Concretely, an agent for managing and controlling vital sensor sends vital data of an object person as stream data to a data stream mining agent. The data stream mining agent analyses the stream data including vital data using data stream mining technology, in real-time. Then the agent detects the health condition of each person. Based on the health condition, agents in sensor devices control the data quality and frequency of data acquisition. By this function, our system can collect vital data of the persons, send and store the data in the database stably, according to the condition of the persons. Moreover, our system can provide a useful information and advice about healthcare for the persons in real-time, according to the person's location and available devices, combining vital data, environment data and knowledge (ontology) on health effectively.

3.3 Agent-based Framework AMUSE

We employ a multi-agent-based framework for service provisioning in ubiquitous computing environments based on concept of symbiotic computing [19]–[21], called AMUSE (Agent-based Middleware for Ubiquitous Service Environment) [22], [23], as a software platform to build user-oriented healthcare support system. The fundamental framework of AMUSE is shown in Figure 2. The basic idea of this framework is "agentification" of all the entities in the ubiquitous computing environments. The agents can perform advanced cooperation and intelligent behavior as follows:

- Recognition of statuses of each entity: Each agent can autonomously observe detailed situation of the target entity such as devices and users, based on the domain knowledge of the entity.

- Coordination of multiple contexts: Multiple entities can effectively exchange context information each other by agent. When agent informs other agent about own context, Inter-Agent Relationship (IAR) is efficiently constructed to reduce unnecessary communication between agents.

- Service composition by combination of entities: Agents can make contract to configure organization of entities in order to dynamically build healthcare support services.

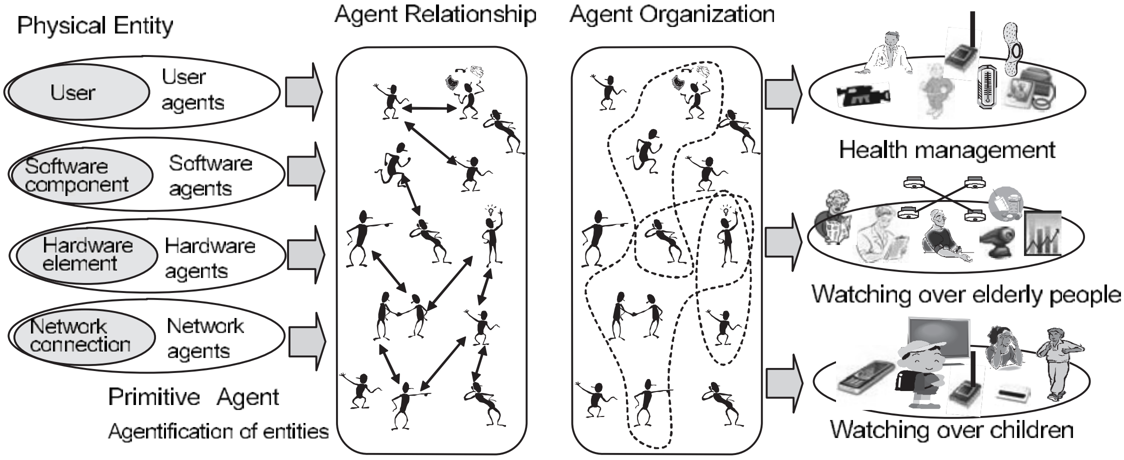

Figure 2: Framework of AMUSE

We have discussed the details of AMUSE in [22], [23], so we omit them in this paper.

4 DESIGN AND IMPLEMENTATION OF USER-ORIENTED HEALTHCARE SUPPORT SYSTEM

4.1 Multimedia system for healthcare support

We suppose the healthcare support system consists of various daily life support systems such as health management system, multimedia supervisory system, remote medical care system, etc. Here, we assume a multimedia supervisory system as one of the healthcare support systems. The multimedia supervisory systems are widespread as care-support systems that enable supervision of children and elderly people from remote sites connected by a wide-area network. Figure 3 shows an example of real-time multimedia supervisory system that delivers live video streaming captured with cameras at the watched person's site, with a PC or a hand-held device at the distant supervisor site.

Our system displays a live video with suitable quality on one of the displays considering the watching person's requirement for the watching over and the status of devices. The agents basically reside in computers, and they manage corresponding entities that are connected to, or are running on the computer. The agents cooperatively work to accomplish QoS that meets to user's requirements on a watching task and device situations. Therefore, our system makes the construction of agent organization by considering the most appropriate camera, the PC with reasonable network connection, and the display devices based on multiple contexts. These contexts are individually maintained by each agent, and its effective coordination would be performed by cooperation among related agents.

4.2 Implementation

In anticipation of our healthcare system, we are developing part of the real-time multimedia supervisory function that delivers live video streaming. Agents were implemented based on AMUSE framework. As for implementation of agents, we used DASH [24]. DASH is an agent-based programming environment based on ADIPS [25]. We also used IDEA [26] for the development and simulation of the agents. It is an integrated development tool for the DASH.

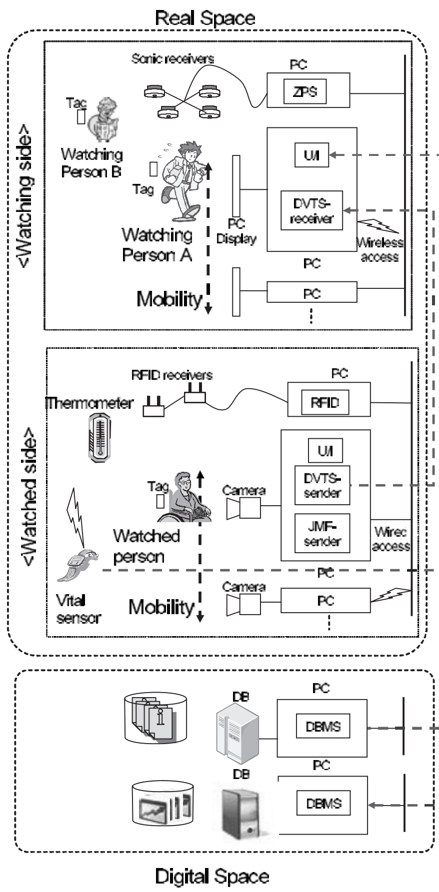

Figure 3: An example of real-time multimedia supervisory system for healthcare support

Table 1: Description of agent library

	Function	Agent Name	Base Process	Description
Hardware	Location information	ZPS	ZPS	Identifying location of tags using ultrasonic sensor
		RFID	RFID System	Identifying location of tags using RFID system
	Image input	DV-camera	DV camera	Control a DV camera to capture video image.
		USB-camera	USB camera	Control a USB camera to capture video image.
	Image output	PC-Display	PC Display	Control a connected PC display to show video image.
		TV	TV set	Control a connected TV set to show video image.
	Audio input	Mic	Microphone	Control a connected microphone to capture audio.
	Audio output	Speaker	Speaker	Control a connected speaker to play audio.
	Computer monitoring	Comp	CPUcheck	Monitoring of the status of computational resources such as CPU usage rate in a target computer.
	Biological information	Bio	Heartbeat	Monitoring target person's heartbeat.
Software	Location information	Location_manager		Management of the up-to-dateness specified by the other agent or application developer.
	Video receiver	DVTS-rec	DVTS application	Video receiving in very high quality by using DVTS Software.
		JMF-rec	JMF application	Video receiving in various formats by using the Java Media Framework (JMF).
	Video sender	DVTS-send	DVTS application	Video sending in very high quality by using DVTS Software.
		JMF-send	JMF application	Video sending in various formats by using the JMF Software.
	Management	Manager		Management of behavior of all the agents in the corresponding PC
	Interface	UserReq	U/I component	Maintenance of the GUI-based software component to acquire the user request directly.
	Human relation	Human-Relation-Ontology	Ontology base	Management of the knowledge on human relationship of users.
	Daily activity support	Daily-Activity-Ontology	Ontology base	Maintenance of knowledge on daily activities of users.
	Common sense support	Common-Sense-Knowledge	Knowledge base	Maintenance of common knowledge used in the target application.
	Situation recognition	Situation-Recognizer		Recognition of situation of a target user.
	Relation recognition	Relation-Recognizer		Specifying human relationship between users.
	Decision making	Advisor		Making decisions of action for a specific application.
	Database management	DBMS	DBMS	Management of the data such as vital sign, environmental information, and location information, and multimedia data.
	Technical knowledge support	Technical-Knowledge	Knowledge base	Management of the knowledge on experts for healthcare.
Network	Network monitoring	W-Net	NETcheck	Monitoring status of an wired network.
		WL-Net	NETcheck	Monitoring status of an wireless network.
User	User manager	User name		Management of requirement, preference, profile, etc. of a user.

We summarize the agent library for AMUSE Framework as shown in Table 1. The agents are categorized into four classes: hardware, software, network, and user agents. The base process is the corresponding entity for each agent. We constructed these agents using ADIPS/DASH.

As for hardware configurations for sensing the location information, we use two sensor types to sense the location information of users in the room: an ultrasonic-based sensor and an RFID system. We use Furukawa Sanki's positioning system Zone Positioning System (ZPS) [27] as the ultrasonic sensor. We also use an active-type RFID system (Fujitsu Software Technologies) [28]. Also, as for delivering live video, we implemented two types of software: DVTS [29] and JMF [30].

5 EXPERIMENTS

5.1 Experiments based on watched person's situation

This section describes some examples of behavior of our system function. We suppose a situation where a watching person (son) watches over a elderly watched person (his father) in remote sites.

In the first experiment, we observed our system behavior based on the watched person's situation. Figure 4 shows the watched person's room. In this room, we set two cameras for delivering a live video: a DV camera and a USB camera as shown in the left picture in Figure 4. The watched person has ZPS tag for sensing tag height and location information. The right picture in Figure 4 shows the ZPS receivers in the watched person's room. We performed some experiments using different situations of the watched person.

Case of normal situation: Figure 5 shows the watching site. The watching person always brings the user terminal. When the watched person is normal situation such as taking meal in the dining room, the nearest user terminal from watching person displays the watched person's image with reasonable quality by USB camera. Moreover when the watching person approaches the plasma television, the live video stays the user terminal. It means agents selected the user terminal and USB camera respect to their personal relationship with the watched person and the watched person's situation (normal situation).

Case of emergency situation: In Figure 6, we compare our system with a location-based service configuration to show the effectiveness of our framework. This case shows emer-

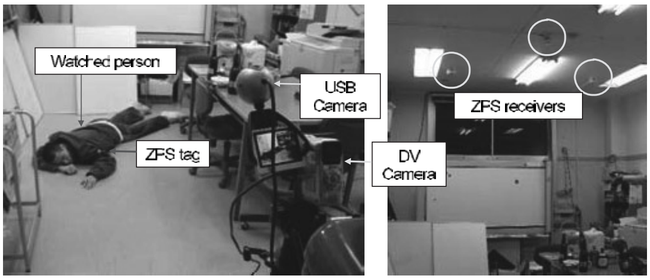

Figure 4: Room setting for experiments based on watched person's situation

Figure 5: The case of normal situation

gency situation of the watched person. The system can understand that this is an emergency situation by inference from the period of time (he has not moved), the location information, and tag's height. For example, the watched person lying in the dinning room is unusual and it is an emergency situation. The left picture in Figure 6(a) shows the behavior of our proposal-based scheme when the watching person moves closer to the plasma television. The video streaming was migrated to the high definition television to show the situation more clearly when the watched person lay down. Then, the most adequate display devices around the watching person, and finally the most suitable display, video streaming software and network connection were selected and configured to deliver the live video. On the other hand, in the case of a location-based scheme, the video service stayed in the user terminal because it was judged as the nearest display, as shown in Figure 6(b).

¿From these experiments, we confirmed the individual agent could decide its own action by considering the situations of the watching person and watched person.

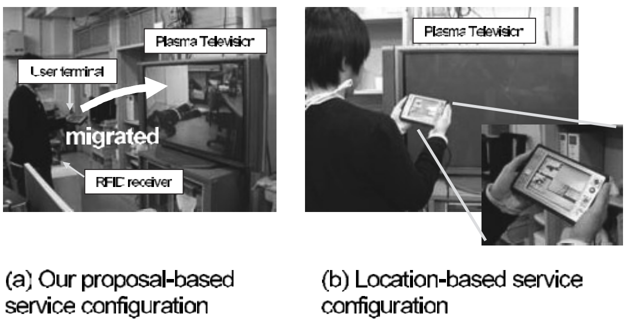

Figure 6: The case of emergency situation

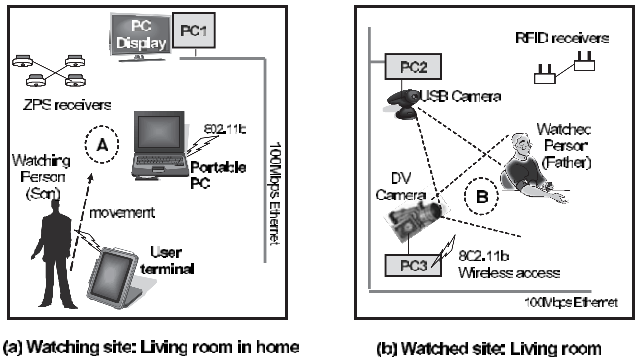

Figure 7: Room setting for experiments based on watching person's requirement

5.2 Experiments based on user requirement

Next, we experimented following application scenarios to evaluate feasibility and effectiveness of our system. Figure 7 shows two experimental rooms.

Figure 7(a) is regarded as the watching person's living room. Additionally, Figure 7(b) shows the room settings of the watched sites. Here, the watching person's user terminal is shown in Figure 7(a). The user terminal is always brought with the watching person. This terminal is selected for receiving the video of the watched person, when other displays cannot be available. A User agent resides in this terminal. The agent monitors the user's requirements and presence. Also, we used ZPS ultra-sonic sensor to sense the watching person's location information. Figure 7(b) is supposed to be a living room in a watched person's home. As for location sensor, we employed an active-type RFID system in this room.

In this experiment, we observe our system behavior based on user requirement. The User agent provides a user interface about the option on the user's terminal. Then, a watching person specifies a user requirement.

We compare our system with a location-based service configuration. In case of a location-based service configuration, the scheme selects the nearest camera and display (except the user terminal) to the watched /watching people, respectively, without any consideration of total quality of the service. Additionally, we fix his father's location for simplification at point "B" in Figure 7(b). Agents cooperatively work together to select the most adequate sets of entities based on the son's requirements and location.

As a user request, the son requires the high smoothness of movement of the video to watch in his father's health condition. When he moves to the location at point "A" in Figure 7(a), a user terminal and a PC display can display the video. It means the point "A" is the service area of the portable PC and the PC display.

In the case of a location-based scheme, because the portable PC was judged as the nearest display, the video service moved to the portable PC from the user terminal, as shown in Figure 8(a). However, the video frame rate was too low to view the movement of his father's body smoothly because it was moved with the same video frame rate parameters as it was in the user terminal.

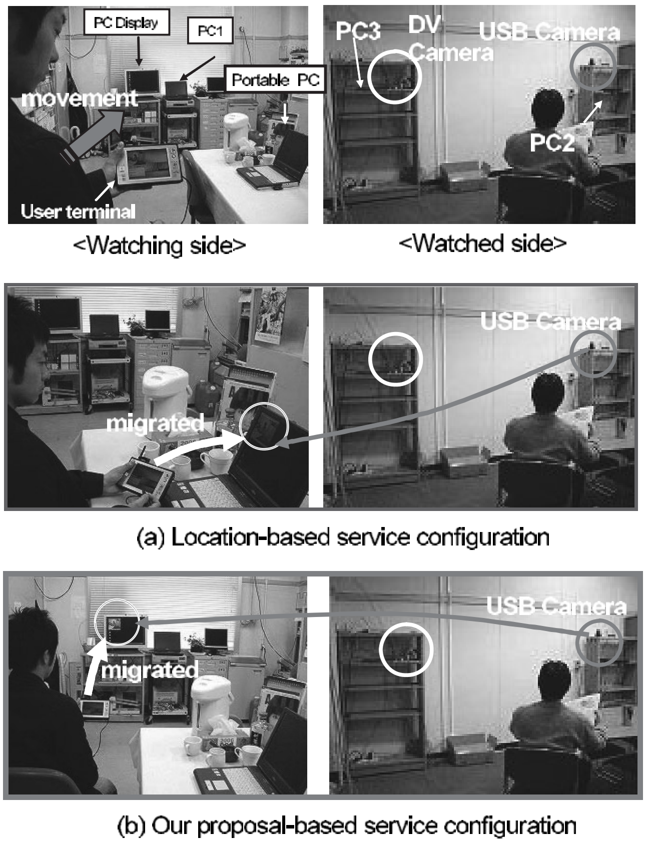

Figure 8: Service configuration in case of high smoothness requirement

At the same time, Figure 8(b) shows the behavior of our proposal-based scheme. Our scheme selected the PC display and the USB camera connected to PC2, with high frame rate to fulfill the user's requirement. As for the network context, PC2 is the best because it is connected by a wired link with 100 Mbps. Additionally, agents recognized that because DVTS software was not installed in PC1 of PC display, the display cannot play DVTS video. Consequently, the USB camera connected to PC2 with the JMF-send agent is selected. In this case, we confirmed that our scheme could deeply consider the multiple contexts, and our scheme could satisfy the user requirement for high smoothness of the video.

5.3 Performance Evaluation

In this experiment, we show the switching time during video service migration for performance evaluation of our system. We used the user terminal with two kinds of access networks: IEEE 802.11g (54 Mbps) and PHS (128 kbps) in this experiment. We measured the switching time during the video service migration in the cases of IEEE 802.11g and PHS, respectively. We measured two cases as follows:

Case-1: The video service migrated from the user terminal to the other PC based on the user request.

Case-2: The video service migrated from the average PC except the user terminal to the other PC (except the user terminal).

When the user terminal used IEEE 802.11g, both Case-1 and Case-2 were able to switch within 3.0 s, on average. It is in an acceptable range for practical use. When the user terminal used PHS, Case-1 took more than 7.0 s in some cases, but Case-2 switched within 3.0 s on average. This reason of the time delay in Case-1 with PHS is a latency of inter-agent message exchange for video service migration between agents in the user terminal and the other PC, during which time the user terminal is receiving the video streaming.

On the other hand, the switching time in Case-2 with PHS was almost the same as the Case-1 using IEEE 802.11g. This result shows the effectiveness that the individual agent could effectively exchange context information while reducing unnecessary communication based on IAR and decide the video service migration by considering the situations of the other agents.

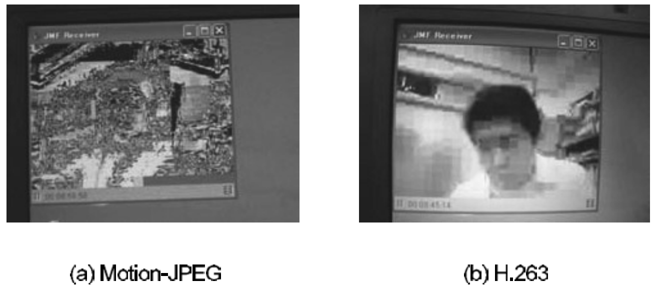

Figure 9: Privacy protection function of video streaming in case of Motion-JPEG (a) and H.263 (b)

5.4 Privacy protection function by controlling quality of service

We think privacy concerns are important aspect in healthcare support system. We are now trying to give privacy protection function to our system. Figure 9 shows the privacy protection function using JMF by controlling the quality level. This function adjust the parameters related the video quality of JMF such as frame rate, bit rate, etc., in accordance with the video format (Motion-JPEG and H.263). In fact, JMF-send agent and JMF-rec agent cooperate to adjust the parameters and the format depending on the situation of network resource. Figure 9(a) shows the case of Motion-JPEG; Figure 9(b) shows the case of h.263. We can see from Figure 9(a) and Figure 9(b), the quality of the video is too low to see the person's face clearly, but we can only judge the person's movement. We consider this function can useful as one of the method to protect the privacy easily.

5.5 Visualization function

Additionally, we are developing the visualization function of the watched person's situation. As an initial development, we are trying to visualize the sensor data such as vital information, location information, and environmental information. We suppose DB agents cooperate with various agents depending on the situation. Here, we show an example of the coordination with a DB agent which is managing watched person's location information. Figure 10 shows a map agent which displays the watched person's position information in his house.

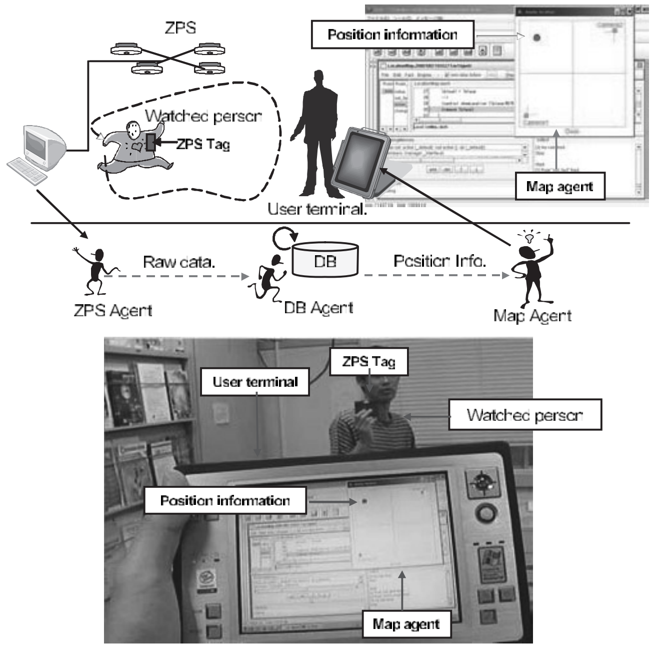

Figure 10: An example of Visualization function

The watched person walks around with a ZPS tag. ZPS agent sends the watched person's location information in the raw to DB agent. The DB agent processes the information and sends the information to Map agent in the watching person's user terminal. The Map agent shows the watched person's position information. We think this function will be helpful for the watching person and the watched person when the camera can't deliver the video streaming and the system think the great deal of the watched person's privacy.

5.6 Discussion

We discuss the effectiveness of our system through the experiments as follows:

Feasibility: We evaluated our proposal-based service configuration scheme. Our scheme could effectively configure service that matches person's requirement, coping with not only the user location information, but also the device status around the users in the ubiquitous computing environment. In our multimedia supervisory function for healthcare support system, heterogeneous entities like display devices, capture devices, PCs, networks, different kinds of sensors, software components, etc., are efficiently integrated in real-time.

And our system can control the privacy level depending on human-relationship and watched person's situation. When the watched person's situation is normal situation, our system protects the watched person's privacy on suitable format; when the emergency situation, our system delivers the high quality video considering multiple contexts.

Effectiveness: Because of the introduction of our agent-based framework, the integration of many entities was successful. Our system provides useful information related healthcare to the object persons and community members. The various types of information are acquired, managed, and provided by cooperation of agents. We confirmed the modularity, the autonomy, and the loose coupling characteristics of the agents from the experiments related visualization function. The function was constructed by agent organizations such as the location information agent, DB agent, and the map agent by easy way. It can adapt to diversity of types of entities and scalability of system size. The system development and extension will be easily accomplished by using this architecture.

6 CONCLUSION

We presented a concept of user-oriented advanced healthcare support system based on multi-agent system in ubiquitous computing environment. The system provides useful information regarding health condition effectively and in user-oriented manner by utilizing knowledge about healthcare and various kinds of information obtained from real space. We also designed and implemented an initial prototype system.

As future work, we would like to advance detail modeling and design to adapt to a variety of the supervisory system such as the healthcare support system and multimedia watching over system for elderly people, and we plan to extend current implementation using various vital sensors, environmental sensors, and DB systems. Moreover we will try to consider the detailed design of data actuation mechanism using data stream mining technology and effective inference mechanism combining an ontology and sensor data. We will integrate these kinds of mechanism into our healthcare support system.

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