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A Wearable Context Aware System for Ubiquitous Healthcare

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***Abstract*—Recent developments of information technologies are leading the advent of the era of ubiquitous healthcare, which means healthcare services at any time and at any places. The ubiquitous healthcare service needs a wearable system for more continual measurement of biological signals of a user, which gives information of the user from wearable sensors. In this paper, we propose a wearable context aware system for ubiquitous healthcare, and its systematic design process of a ubiquitous healthcare service. Some wearable sensor systems are introduced with Zigbee communication. We develop a context aware framework to send information from wearable sensors to healthcare service entities as a middleware to solve the interoperability problem between sensor makers and healthcare service providers. And, we propose a systematic process of design of ubiquitous healthcare services with the context aware framework. In order to show the feasibility of the proposed system, some application examples are given, which are applied to remote monitoring, and a self check service.**

I. Introduction

Recent developments of information technologies are leading ubiquitous healthcare services to reality, which mean healthcare services at any time and at any places. A wearable system can be a key system for a ubiquitous healthcare service because it makes possible more continual access to information about its user. For a ubiquitous healthcare service with a wearable system, information of the user gathered from wearable sensors is sent to healthcare service entities via a network. A middleware is required in order to handle the problem of interoperability between information from sensors and ubiquitous healthcare services. And, the middleware should deal with a service provision mechanism from ubiquitous service providers to wearable systems.

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Some context aware frameworks were developed as a middleware for services in the ubiquitous environment. Kermarrec and Couderc proposed a general infrastructure to improve the level of a delivered service despite environment variations, which is based on the concept of a contextual object in distributed client/server information systems. An information server has variants of contextual objects which can be identified by context attributes, and a variant selection algorithm is applied to select a contextual object according to the desired context attributes from an application [1]. Dey developed the context toolkit for context application programming, which has the encapsulated programming components like context widgets and context interpreters to deal with contexts more efficiently in the distributed environment. The context toolkit gives programmers the programming tool which makes it possible to convey contexts without any dependency between sensors and services by the abstraction of sensor values [2]. Woo et al. proposed the classification of contexts via 5W1H (Who, When, Where, What, Why, How) and the concepts of UbiService and UbiSensor for utilizing context information in the distributed computing environment. By classifying contexts into some classes, they made more efficient process of the context awareness [3]. Yau et al. proposed a middleware which triggers appropriate actions directly in an application. The RCSM (Reconfigurable Context Sensitive Middleware) gives an object-based development framework, and enables context-sensitive applications with adaptive object containers (ADCs) for runtime context data acquisition, monitoring and detection [4]. Ranganathan proposed a context-aware middleware which is based on a predicate model of context, which makes agents use rules or machine learning approaches to decide behavior according to different contexts. They used ontologies for better semantic interoperability between different agents, as well as between different ubiquitous computing environments [5]. Gu et al. proposed a service-oriented context-aware middleware (SOCAM) architecture: an OSGi based infrastructure for context aware applications, which gives the platform independence, hosting of multiple services from different providers, various levels of system security, etc. And, they proposed a scalable ontology-based context model using OWL (Web Ontology Language) and a reasoning mechanism to reason high-level contexts from low-level sensor information [6].

In spite of the previous studies about a context aware framework in the ubiquitous environment, there are few studies related with ubiquitous healthcare, and a systematic way of design of healthcare services with wearable systems. In

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this paper, we propose a wearable context aware system for ubiquitous healthcare in the ubiquitous environment, and its systematic process of design of ubiquitous healthcare services.

The outline of this paper is as follows. In Section 2, we describe the proposed wearable context aware system and the service provision mechanism. In Section 3, we present the proposed context aware framework and its systematic process of design of ubiquitous healthcare services. In Section 4, in order to show the feasibility of the proposed system, we give examples of applications to a remote monitoring service and a self-check service. And, finally, some concluding remarks and discussions are given for future research in the last section.

II. Wearable Context Aware System

The proposed wearable context aware system for ubiquitous healthcare is composed of three parts: wearable sensor systems, wearable computers and communication modules. The wearable sensors are connected to wearable computers via Zigbee communication. The measured bio signals are transmitted to wearable computers, and processed into preliminary contexts. The wearable computer processes the data of bio signals of a user into the abstracted information, i.e., a context. The preliminary context can be converted to higher level context by reasoning engine or other methods.

The wearable context aware system is connected with service providers via a network, and ubiquitous healthcare services are provided via some service provision mechanism. In Fig. 1, we depict overall configuration of the network between the proposed wearable context aware system and healthcare service providers.

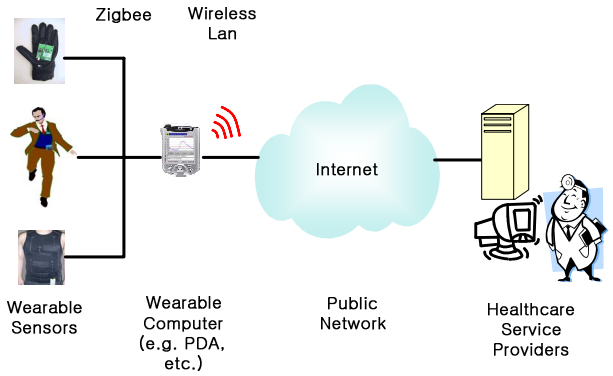
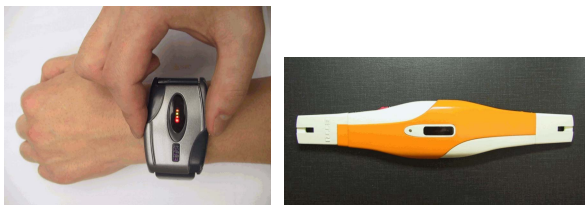


Fig. 1. Overall configuration of the network between the proposed wearable context aware system and healthcare service providers.

A. Wearable Sensor Systems

We develop two types of wearable sensor systems: a watch type sensor system and a chest belt type sensor system. The watch type sensor system is attached to the wrist of a user like a wrist watch. It has an ECG (Electrocardiogram) sensor, a PPG (photoplethysmograph) sensor and a SKT (Skin Temperature) sensor. It has a MCU and a 10 bits AD converter, a Zigbee communication module. The chest belt type sensor system is attached to the chest of a user like a chest belt. It has an ECG sensor, a respiration sensor, a SKT sensor and a three axis acceleration sensor. Both systems are depicted in Fig. 2. The signals gathered from the systems are used to make features like pulsation, respiration, etc.



(a) (b)

Fig. 2. The developed sensor systems. (a): a wrist type sensor system. (b): a chest belt type sensor system.

B. The Wearable Computer and Communication Modules

We use a PDA as a prototype of a wearable computer. The PDA has a 400MHz XScale processor, a 64Mb RAM, IEEE 802.11b wireless LAN capability and Zigbee communication capability through a serial port. The Zigbee module is used for communication with wearable sensors, and the wireless LAN module is used for communication with ambient sources of contexts and service providers. The proposed context aware framework processes the data of bio signals of a user into the abstracted information, i.e., a context in the wearable computer for interoperability between information from sensors and service providing entities, which will be described in the next section.

C. Types of ubiquitous healthcare services

We classify ubiquitous services into two categories: local services and remote services. Local services are given to users by a wearable computer located in a personal are network. The code for a local service is executed in a wearable computer, which is downloaded through the wide area network from ubiquitous service providers. Contexts are processed by a local wearable computer, and a health care service is provided according to the contexts. Remote services are provided in remote servers operated by service providers. Service entities are located in remote service servers. The contexts should be transferred via the wide are network, which are needed for the remote service.

III. Wearable Context Aware Framework

We propose a wearable context aware framework as a middleware to solve the problem of interoperability between sensors and services and ubiquitous service provision of both types of ubiquitous healthcare services: local services and remote services.

A. Context Modeling

Context modeling should be standardized between service providers and sensor makers. A context model is very dependent on a provided service, that is, domain-dependent. Therefore, it is required to deal with multiple context models in a context aware framework. We design an ontology based

context model for ubiquitous healthcare services. Using the OWL (Web Ontology Language), we design the following ontology based context model. The health care ontology is composed of Person ontology, Device ontology and Health ontology. The Person ontology is used to identify a user, a doctor, user's family or friends. The Device ontology is used to describe a wearable sensor system, e.g., sensors and PDA, etc. The Health ontology is used to describe the health status of a user. The health status is recognized via the pulsation, respirations, body temperature, blood pressure and consumed calories of a user. The Person ontology owns the Device and the Health ontology. The relations among classes are depicted in Fig. 3.

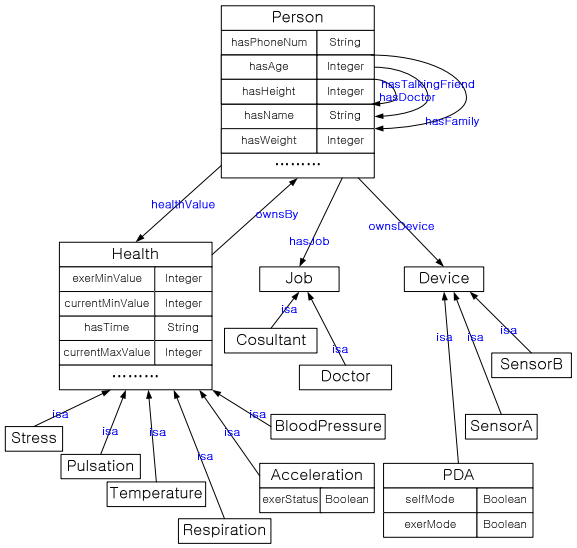


Fig. 3. Ontology based context model.

B. OSGi based Context Aware Framework

As a middleware between sensors and services, we propose a context aware framework composed of entities as follows:

1) Context Provider: A context provider makes the preliminary context based on the context model using sensor values. The context provider is connected to wearable sensor via Zigbee communication, and performs the abstraction of sensor information.

2) Context Integrator: It is complicated for a programmer of a service to program codes for acquiring multiple contexts. A context integrator is the entity to acquire multiple contexts instead.

3) Context Interpreter: Services may need higher level contexts rather than contexts that can be measured via sensors. A context interpreter is the entity to derive more abstracted contexts from sensed contexts by using a domain knowledge or heuristics. In this paper, we use JESS for reasoning engine.

4) Profile Manager: A profile manager deals with user profiles and service profiles. User profiles are given by a user or sensors about a user. The profile manager gives some method to save and retrieve service profiles for the convenience of service efficiency.

3) Framework Basic Function Manager: The framework basic function manger is a core of the context aware framework. It manages lists of context providers, context integrators, context interpreters and a profile manager. It processes requests for contexts from context consumers using the lists.

The proposed wearable context aware framework is based on the OSGi platform, which is a kind of Java based component service framework. Every entity of the context aware framework is made in the form of an OSGi service bundle. The OSGi platform manages life cycles of entities of the context aware framework. And, using service registration capability of the OSGi platform, the framework basic function manager of the context aware framework can manage the lists of the context providers, context integrators, context providers and profile managers. Furthermore, the service provision mechanism of the OSGi platform is used for ubiquitous local services, by downloading service codes to a local wearable computer from remote servers by ubiquitous service providers. This gives the coherency and convenience to programmers of services and entities of the context aware framework.

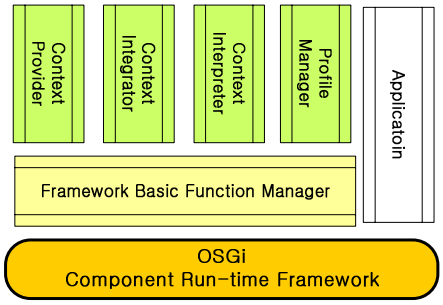


Fig. 4. The OSGi based context aware framework.

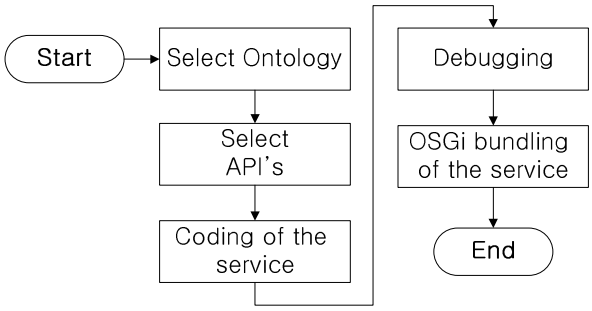


Fig. 5. The systematic process of design of services.

C. Systematic Design Process of Services

In order to make a ubiquitous healthcare service or entities of the context aware framework, we use a systematic process of design of services. By following the process, easier design of the entities of the context aware framework is possible, which invokes the popularization of the ubiquitous service. First, a programmer should select the appropriate ontology for a context model of a service domain. Second, the appropriate API's of the context aware framework are selected according to the application domain of a ubiquitous service or entities of the context aware framework. And, using the API's, the

programmer can make codes for ubiquitous services or entities of the proposed context aware framework. After debugging of the codes, the codes should be made as an OSGi service bundle. Then, the ubiquitous services or entities of the context aware framework can be provided by the OSGi service provision mechanism.

IV. APPLICATIONS

In order to show the feasibility of the proposed system, some application examples are given, which are applied to a remote monitoring service and a self check service.

A. *Remote Health Monitoring Service*

In case of the remote health monitoring service, wearable sensor systems gather the bio signals of ECG, PPG, respirations and SKT. It transmits them to context providers of the wearable computer via Zigbee communication. Then, the context providers produce the contexts of Heart rate, blood pressure, respiration and body temperature. We developed the remote health monitoring portal service, where users should subscribe to the service via WWW, and doctors can monitor and utilize the transmitted contexts of bio signals of the user either in real time or in the future. The remote health monitoring service is an example of the remote ubiquitous service, because the service entity is located in the remote web server.

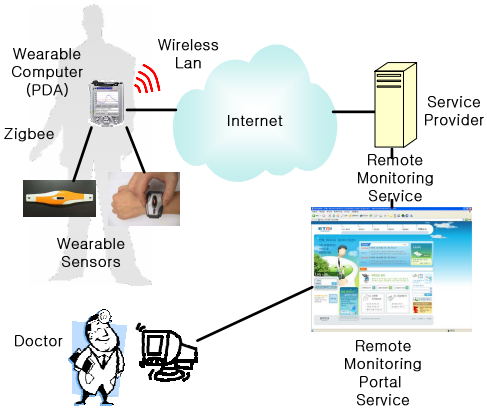


Fig. 6. The remote health monitoring service as a remote service.

B. *Self Health Check Service*

For the self health check service, the service entity should be downloaded to a wearable computer via an OSGi service provision mechanism. Wearable sensor systems measure and send the bio signals of ECG, PTT, respirations, SKT to the wearable computer via Zigbee communication. It is converted to the Heart Rate, respirations, Temperature, PTT in context providers in the wearable computer. A context aware framework connects the preliminary personal contexts to the self health check service entity which is a local ubiquitous service. The context interpreter can determine the health status of the user via reasoning from preliminary personal contexts. The user can check his or her health status from the GUI in the wearable computer.

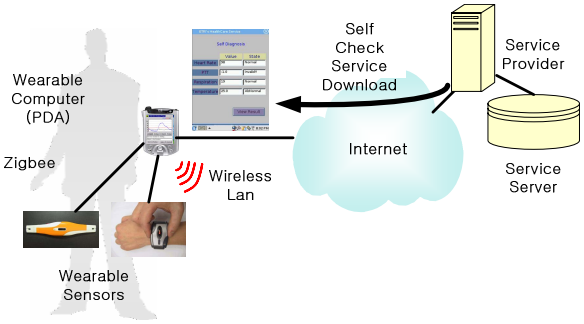


Fig. 7. The self health check service as a local service.

V. CONCLUDING REMARKS AND DISSCUSSION

In this paper, we proposed a wearable context aware system for ubiquitous healthcare service. Wearable sensor systems were developed for the wearable context aware system: a watch type sensor system and a chest belt type sensor system. The context aware framework was proposed as a middleware between sensors and service entities in the wearable system. Using the OSGi platform, the wearable context aware system makes possible both local ubiquitous services and remote ubiquitous services. The ontology based context model was used for semantic interoperability between sensors and services. We proposed a systematic design process of the ubiquitous service and the entities of context aware framework. By following the process, easier design of the entities of the context aware framework is possible, which invokes the popularization of the ubiquitous service. To show the feasibility of the proposed system, we presented two examples of the application to the remote health monitoring service and the self health check service. For future research, we will study about standardization of the ontology context models for healthcare services, and about more efficient structure for context aware service provision.

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