# A BPM-BASED MOBILE U-HEALTH SERVICE FRAMEWORK

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Abstract: The integration of mobile bio-sensors and cellular phones opens a new horizon for healthcare service. Mobile u-health service, which usually incorporates mobile bio-sensor attached cellular phones, provides users real time healthcare services at the right time in the right manner. While the u-health services may look different from the service point of view, they often share many common features at various levels such as the service structure, unit service, and data levels. Thus, it is necessary to have a common platform on which various u-health services can be developed by effectively sharing and reusing the common features and services rather than developing the services independently from the scratch. In this paper, we propose a mobile u-health platform that provides core functions and facilities to develop mobile u-health services. Main elements of the platform include the u-health ontology and common data structures, and Business Process Management (BPM) based service integration framework. The platform provides commonly reusable features and functions in developing u-health services. According to the early evaluation, our platform turned out to have strength in terms of service flexibility, accessibility, evolvability, reusability, adaptability, interoperability and guideline provision for developing u-health services.

## 1 INTRODUCTION

The integration of mobile bio-sensors and cellular phones opens a new horizon for healthcare service. It enables us to provide various healthcare services in mobile environment. Actually, couple of mobile u-health services are developed and announced to the public. But, currently available mobile u-health services are very limited in terms of scopes and types of the services. This situation will be changed as more mobile bio-sensors become available and the number of mobile u-healthcare users increases.

Meanwhile, due to the lack of commonly available mobile u-health service development and running platform, current mobile u-health services are usually developed in ad hoc and separate manner. Although u-health services may look different from the service point of view, they often share many common features at various levels such as the service structure, unit service, and data levels. Thus, it is necessary to have a common platform on which various u-health services can be developed by effectively sharing and reusing the common features and services rather than developing the services independently from the scratch.

In this paper, we propose a mobile u-health platform that provides core functions and facilities to develop mobile u-health services. Main elements of the platform include the u-health ontology and common data structures, and Business Process Management (BPM) based service integration framework. The platform provides commonly reusable features and functions in developing u-health services.

The platform has several unique features. First, the platform interprets and treats mobile u-health service as service process and it extends BPMS to healthcare service. As a consequence, the platform can provide functions and facilities of general Business Process Management System (BPMS). In regard with the u-health service process, we define a typical mobile u-health service process template and deploy the process template on the platform. Second, the platform is equipped with a very unique matrix based patient group identification method. The method is quite useful in mobile environment in which less precise bio-signals data is frequently gathered from a large number of users. Third, the platform provides several advanced features and functions by incorporating ontology technologies in

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defining mobile u-health services and disease inferring processes.

We implemented the prototype of the proposed platform and evaluated the prototype based on the various software design criteria. According to the early evaluation, our platform turned out to have strength in the aspects of service flexibility, accessibility, evolvability, reusability, adaptability, interoperability and guideline provision for developing u-health services.

# 2 RELATED WORK

Konstantas et al. (Konstantas et al., 2006) have presented a Java-based service platform for remote monitoring of patients. They collect patient data using medical sensors integrated into the system which captures six different bio-signals: ECG, HRV, pulse oximetry, temperature, marking, respiration, and motion/activity. The captured bio-signals are delivered to remote healthcare experts for analysis. However, the system does not provide any means to manage the health care process between the experts and the patients.

There were some attempts to use a workflow management system or Business Process Management System (BPMS) for the integration of the Patient Record Manager (PRM) module and the Personal Organizer (PO) system in healthcare support (Pappas et al., 2002). Healthcare and emergency response organizations are the users of such solutions. One of the drawbacks of a healthcare system without BPM is insufficient handling of incomplete task definitions (Broens et al., 2005).

Oliver et al. (Oliver and Flores-Mangas, 2006) have designed and developed MPTrain, a mobile phone based system that utilizes the effects of music in physical exercises. MPTrain enables users to more easily achieve their exercise goals by constantly monitoring their physiology such as HRV, and by selecting/playing music with specific features that make the users speed up, slow down or keep the pace to maximize the exercise results.

The work done by Jovanov et al. (Jovanov et al., 2003) is closely related to the healthcare monitoring. They capture HRV to quantify the levels of stress for a group of individuals undergoing military training. They collect HRV data of military personnel prior to, during and after training and assess their stress levels and predict their stress resistance.

However, none of the work support a systematic approach in developing mobile u-health services by using a common u-health service platform like the one described in this paper.

# 3 MOBILE U-HEALTH SERVICES

A mobile u-health service system is a total system that enables u-health services to be coherently provided to the users. The system integrates various components such as bio-sensors, cellular phones, associated software, and devices that are essential for u-health services. In this section, we describe the core components that constitute mobile u-health services.

We have identified the main categories of the core components that play essential roles in providing u-health services. Bio-data gathering and management, bio-data analysis, and knowledge extraction and decision support are the service categories that we identified based on the steps or roles involved in the u-health service process.

## 3.1 Bio-data Gathering and Management

A mobile u-health service starts its function with periodically or randomly gathering input data i.e. capturing the bio-signal data from users. We use some bio-sensors that are wearable by the users or imbedded into cellular phones. Thus, the bio-sensor devices and cellular phones, which act as a gateway between the bio-sensors and the u-health server, are the essential components for gathering input data.

Besides, questionnaires that can be provided via cellular phones are necessary to obtain information that cannot be gathered from bio-sensors. The physical symptoms that a user experiences, the location of the user, and the weather information are examples of such information that need to be obtained directly from the users by using the questionnaires. We have developed a generic questionnaire composer to accommodate various symptoms and environmental information in making questionnaires.

Our mobile u-health service platform provides the sensing modules and questionnaire interfaces independently from the core functionality of u-health services. This improves the reusability of the sensing modules and questionnaires for different healthcare services.

## 3.2 Bio-data Analysis

Since huge amount of bio-data need to be gathered and analyzed in mobile u-health services, it is essential to have an efficient data structure that allows the system to effectively store and manage bio-data. We investigated that a matrix is one of the good candidates for storing and analyzing a large quantity of data. We devised a bio-signal and symptom combination matrix, in which the appearances of bio-signal and symptom combination pairs of a normal user group and those of a patient user group are registered. We call the matrix as the Disease Combination Appearance Probability (DCAP) matrix. Two DCAP matrices are created, one for normal groups, and another for patent groups. The accumulated data in DCAP matrices becomes the basis of the next step of the u-health service process, the knowledge extraction and decision support.

### 3.3 Knowledge Extraction and Decision Support

Once a large amount of bio-data is accumulated, knowledge extraction and decision support for diagnosis can be provided by using data mining technology. Sometimes, we can use well established health indices to diagnose certain diseases to support some u-health services. However, in many cases, new health indices may need to be developed by performing machine learning or pattern recognition based on the accumulated data.

For the accumulation and management of bio-data and information obtained from questionnaires, we have developed data ontology. Based on this data ontology, symptom, disease and bio-signal data can be archived in a structured manner. Some additional information such as a weight value to represent the degree of association between each input data and a certain disease type is assigned to the data ontology. Note that the weight values are defined not by users but by domain experts. The data ontology grows as new services and/or disease information are incorporated, and this contributes to make our platform evolvable.

One assumption that we made in identifying health indices is that diseases can be diagnosed based on the combination of bio-signals and symptom information. Another assumption is that bio-signals and symptom data of normal and patient groups can be obtained in some way. If the difference between the data gathered from the normal group and the patient group is obvious, the interrelation patterns between bio-signals and symptoms provide good criteria to classify users into the two groups. A statistical equation is devised based on the DCAP matrices to discern a normal group from a patient group. Once bio-signals and symptoms of a disease or a service are stored in DCAP matrices, (Eq. 1) is used to compute the probability for a person who has the CP(p) bio-signals and symptom pairs to belong to the patient group of the disease. X(p) and Y(P) denote weight vectors of bio-signals and symptoms respectively. We leave the detailed explanation to our previous work and we do not delve into the details in this paper.

$$P(p \in \text{Patient Group} \mid CP(p)) = \sum_{i=1}^{m}\left[\frac{X(p)_i}{\sum_{j=1}^{m} X(p)_j}\cdot\left(\sum_{u=1}^{n}\frac{Y(p)_u \cdot DCAP(p)_{i,u}}{\sum_{v=1}^{n} Y(p)_v}\right)\right] \quad \text{(Eq. 1)}$$

## 4 MOBILE U-HEALTH SERVICE SCENARIO

Fig. 1 illustrates the generic service scenario for mobile u-health services. In the first step of the service scenario, users fill out questionnaires to provide information about physical symptoms and their environments, which cannot be obtained from bio-sensors. The sensors embedded in cellular phones capture necessary bio-signal and relay the data to the u-health server.

After gathering bio-data from questionnaires and sensors, a mobile u-health service process is initiated by an associated BPM engine. The next activity of the scenario process is to store the relayed data to a database so that the history of bio-data of a person can be persistently kept for further analyses.

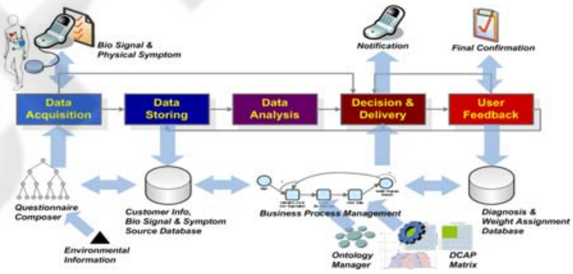


Figure 1: Mobile u-health service scenario process.

In the data analysis and decision support steps, the data ontology manager, which keeps semantically structured data for a specific set of diseases, plays a key role in identifying potential diseases based on the symptoms and bio-signals. For each symptom and bio-signal, the data ontology manager assigns a weight value that represents the degree of association between the symptom or bio-signal and a certain disease.

The final diagnosis decision is made by (Eq. 1). The computed probability is delivered to the user to show whether the user belongs to the patient group or not. One of the unique features of our approach is the user feedback mechanism. Using the feed back mechanism, users can send their feed back on analysis results (the diagnosed diseases) as the response to the system. Based on this feedback data, the system adjusts weight values of corresponding symptoms and bio-signals to provide more personalized services.

The u-health service scenario itself, and the data ontology and the DCAP matrix components are independent from any specific u-health services. Therefore, the platform we designed is considered to be a general platform. In other words, the u-health service scenario and its supporting components can be used for a variety of u-health services. A mobile u-health service for specific disease can be implemented by extending the service scenario. Please see Section 6 for more details.

## 5 PLATFORM ARCHITECTURE

The mobile u-health service platform is a middleware that enables the integration of diverse services by using BPM. It serves as the hub to integrate techniques and functions that are associated with mobile u-health services, and provides an environment to develop and run the u-health services. Fig. 2 illustrates the architecture of the platform that shows the major components and the connections to the surrounding elements in the u-health service framework.

Since cellular phones play the role of a gateway between bio-sensors and servers, mobile message handling is essential for the platform. The mobile message handling module relays all the messages from bio-sensors to the server. Not only the bio signal data but also service request messages are delivered by the message handling module. Sometimes, it contributes to filter out some noise signals from the received messages.

The bio-data delivered to a server is stored and managed by the huge temporal data management module. The bio-data is stored in diverse forms so that various services can utilize the data to perform their functions.

Data mining and pattern recognition techniques are used to identify health index from the accumulated bio-data. Also, an external or internal expert system may refer to the data as feedback information. In order to support this, the database schema of the temporal database needs to be designed to satisfy the requirements of data mining or pattern recognition techniques and expert systems.

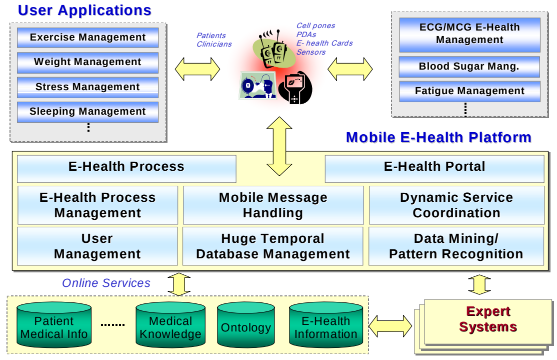

Figure 2: Mobile u-health service platform architecture.

As explained in Section 4, in order to develop a mobile u-health service on the service platform, the u-health service should be defined in a form of process containing steps like bio-data gathering, storing, analysis, and result reporting. The u-health process block in Fig. 2 denotes a set of mobile u-health processes derivable from the u-health service scenario process explained in Section 4.

The u-health process definition tool allows developers to easily define new mobile u-health services. Mobile u-health services defined in a form of process are controlled and enacted by the u-health process management module. The u-health process management module provides not only the enactment function but also monitoring and administration functions for u-health processes.

The mobile u-health management module and u-health process definition tool play a key role in making the platform evolvable. When a new mobile u-health service process is defined, reusable process templates, steps, and data structures are identified and registered to the server for later use. The management module ties together a set of u-health services into a group by specifying execution dependencies and the dataflow between the services. There may be also some constraints that prevent a particular service to be initiated until some other services finish their functions.

The user management module is essential for providing personalized service to individual users. The user management module stores user profile information such as age, gender, and occupation. Since a user is a participant in a mobile u-health process as well, this module is closely connected to the participant information in the u-health process management module.

The dynamic service coordination module executes a service process by initiating and synchronizing services during runtime. It also ensures reliable u-health service execution by replacing one service with an alternative one when a fault occurs in the service or the user's requirements are changed. Data mining and pattern recognition functions may need to be developed for specific u-health services. Whenever such functions become available, they are placed on the data mining/pattern recognition module. An expert system engaged with a u-health service may need to access the functions in the data mining/pattern recognition module to get a decision making support.

Mobile u-health services are accessible not only from mobile devices, but also through a Web browser. Web users can connect to a healthcare Web portal, and access their health information. The healthcare portal also provides useful services such as registering user information, composing questionnaires, and browsing expert advices. Especially, the Web portal allows users to access services that cannot be provided through mobile devices due to the limitations of the devices such as the small screen size, and memory and processor constraints.

# 6 IMPLEMENTATION

## 6.1 Mobile u-Health Modeling Tool

We have implemented a prototype of the u-health process modeling tool that allows application developers to semi-automatically compose mobile u-health services.

Fig. 3 shows the prototype of our mobile u-health process modeling tool. The tool is implemented in Java™ on Eclipse Foundation's Eclipse™ platform. Part (a) of Fig. 3 shows the canvas of the visual business process editing tool. The tool graphically shows the basic u-health service process template, and allows application developers to specialize and extend the process to meet their requirements. In the course of defining the process, the process modeling tool recommends a set of candidate services that can be used to implement each step of the process, and are interoperable with other services that are already put in the process. It also automatically inserts adapters and converters when it finds some syntactic and semantic mismatches between services in the process. Part (b) of the modeling tool is the service recommendation tool that shows a list of candidate services for each step in a process. When a user marks a service in a service process, the tool lists the services that are interoperable with the marked service. Part (c) of Fig. 3 is the ontology-hierarchy browser that allows developers to browse through the service hierarchy.

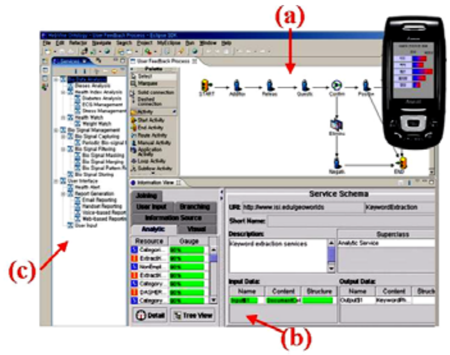


Figure 3: Prototype of the service composition tool - (a) Visual business process editing tool; (b) Service recommendation tool; (c) Ontology-hierarchy browser.

## 6.2 Mobile u-Health Ontology Manager

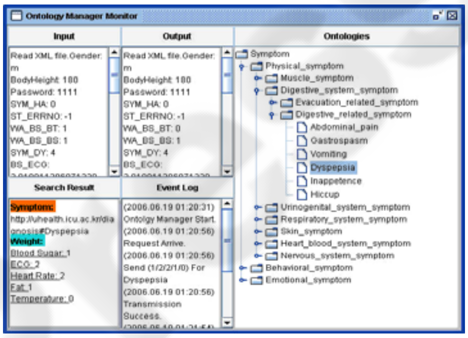


Figure 4: Ontology manager interface.

As explained earlier, in our platform, u-health data such as symptoms, diseases, and bio-signals, are systematically managed by constructing their ontology. In addition, services are classified and managed based on their functional ontology. The ontology manager allows experts to easily manage the u-health ontology. Fig. 4 shows the user interface of the ontology manager. By using the tool, experts can browse, add, remove, and search u-health ontology.

## 6.3 Mobile u-Health DCAP Matrix

In our u-health service platform, the interrelation patterns are identified in the learning and diagnosis stage based on the patterns that is constructed in the prediction stage. In the learning stage, interrelation patterns of bio signal data and physical symptoms of the normal and patient groups are identified. We assume that enough learning data for the identification of interrelations is available for this stage.

In the learning stage, interaction frequencies of bio-signals and physical symptoms from the normal and patient groups are counted and registered in the Combination Interaction (CI) matrices. Each CI matrix contains combination patterns of specific bio-signals and physical symptoms of the normal or patient group with frequency scores. We integrated both CI matrices into the DCAP matrix. In the DCAP matrix, each element has a probability which means how likely the combination pattern of the element can be shown in a patient group. In the prediction stage, bio signals and physical symptoms of an unidentified person are submitted to the prediction system. Then, the prediction system determines how likely the person can be categorized into the patient group. Since the DCAP matrix is constructed based on the CI matrix, we can easily figure out which bio-signal and physical-symptom combinations contribute to a certain diagnosis. In Fig. 5-(b), shaded areas are corresponding bio-signal and symptom combination elements, and a probability, ranging from 0 to 1, is calculated by using (Eq. 1).

The DCAP matrix enables diverse forms of bio-signals and physical symptoms to be used for analyses. As shown in Fig. 5-(a), users can compare their position in the matrix with those of others. In addition, when we use the DCAP matrix, finding primary bio-signal and physical symptom pairs that contribute for the user to be classified into the patient group is relatively easy. As a result, the prediction system can show the causes of a certain disease to users in a comprehensive manner. The more clinical data is accumulated in the platform, the more services the platform can provide in the future.


Figure 5: Disease combination appearance probability matrix – (a) Disease distribution chart for a learning set; (b) Test result for a user health condition by the DCAP matrix.

## 6.4 Mobile Client

Due to the diverse types and characteristics of bio-sensors and various application scenarios, there are many different requirements imposed on mobile u-health systems. As a mobile gateway, a mobile device is responsible for collecting data from sensors by periodically sensing the human body.

Once a communication link is established, bio-data and functions are delivered to the u-health server using the wireless interface. The interface sends and receives XML messages to and from BPM. An XML message can a flexible structure to facilitate transmission of different data types and formats generated based on various bio-signals and physical symptoms. By parsing the XML message, the server classifies bio-data into several types and then the server responds with the results of classified bio-data in an XML message.

After forwarding bio-data to the server, the application changes its state to the stand-by state until it receives a response message from the server. No event or signal can be pushed to the client asynchronously. A process polling mechanism is used to continuously pull the event of clients' requests to the decision support step of the u-health service process. When the server process is completed, the result is delivered to the client.


Figure 6: WIPI Application Mounted on KTF Emulator & Samsung Anycall SPH-V8900.

Once the client receives the probability of a disease, the result is graphically displayed on the mobile device. Figure 6 shows a graph displayed on a cellular phone after receiving the results from the server. If the user does not agree with the results, he/she can send a feedback to the server to revise his/her own weight vectors. The DCAP matrices are updated if the feedback data is sufficiently accumulated.

# 7 EVALUATION

We considered some quality attributes in designing the mobile u-health service platform, which is a large-scale service platform. We think that flexibility, accessibility, evolvability, reusability, adaptability and interoperability are the essential requirements for large-scale service platforms.

Table 1: Evaluation of the Mobile u-Health Service Platform.

| Core Components / Design Goals | Bio-data gathering and management | | Bio-data analysis | | Decision support |
|---|---|---|---|---|---|
| | WIPI | Web Portal | Ontol-ogy | DCAP Matrix | BPM |
| Flexibility | ○ | △ | ○ | ○ | ○ |
| Accessibility | ○ | ○ | × | × | △ |
| Evolvability | N/A | N/A | ○ | ○ | △ |
| Reusability | △ | ○ | ○ | △ | ○ |
| Adaptability | △ | △ | △ | ○ | ○ |
| Interoperability | ○ | ○ | △ | △ | ○ |

Remarks: ○: Supported, ×: Not Supported, △ : Insufficient, N/A: Not Applicable

Table 1 summarize these quality attributes and explain how the core components of our service platform contribute to satisfy those requirements. The following sub-sections discuss the design rationales of our platform to make it satisfy each of the quality attributes.

## 7.1 Flexibility

There are some reasons why the mobile u-health service platform needs to be flexible. Different sets of bio-sensors such as ECG, HRV, and temperature sensors need to be supported for different u-health services. Furthermore, some of the sensors may need to be replaced with other types depending on the mobile-device types and some other constraints. In addition, the functionality provided by the platform or the user interface on a mobile device may need to be customized for a specific user group. Also, the bio-signals and symptoms that the healthcare server handles may need to be changed based on the disease types to cover by specific u-health services.

In order to support flexibility, we have developed a Web-based questionnaire composer. It can easily accommodate new questionnaires or updates of questionnaires for new u-health scenarios. In addition, since we use the BPM process modeling tool for the definition of u-health service processes, we can easily update the defined process when a change is required. This enables the platform to be used for a variety of u-health services with different scenarios. The ontology-based data management and the DCAP matrix are the features that improve flexibility of our platform as well. The structure of ontology and DCAP matrix can be dynamically changed based on users' feedback information.

## 7.2 Accessibility

The multi-channel approach, which makes users' health information accessible via both mobile and Web-based interfaces, supports a good access environment that enables the benefits of hybrid accessibility. In the healthcare service environment, a real-time and mobile disease-checking function can be supported using mobile devices whereas the in-depth analysis of the disease can be provided on the Web. This makes the users to access their health information in various degrees of detail.

## 7.3 Evolvability

As discussed in Section 3, the data ontology evolves as new data and feedback information from users are accumulated. In addition, the DCAP matrices used in our u-health service platform are also evolvable. According to the feedback on the analysis results, the DCAP matrices appropriately change their values for more precise and personalized analyses.

## 7.4 Reusability

The BPMS-based service development mechanism makes service components reusable for various types of u-health services. In other words, when a new mobile u-health service is defined with the u-health process definition tool, developers can reuse various service components, and other assets in different abstraction levels. Process templates, activities, applications pertaining to an activity, and data structures are the reusable assets in our platform. When we consider that most u-health service processes shares the basic u-health service scenario described in Section 4, many components of a u-health service process can be reusable by other u-health processes. Since our platform is based on BPMS, it is competitive in supporting reusability.

## 7.5 Adaptability

The circumstances and environment surrounding mobile u-health services are ever changing. New bio-sensors, which produce new forms of signals or signals never handled before, may become available, and new service scenarios may be developed. For example, a mobile u-health service may be developed to handle only a single type of sensor. But sometime it may need to handle multiple sensors in a bundle. Then, the implementation of the u-health service needs to be modified to cope with the changes. Since our platform maintains a property file that keeps the descriptions about the sensor types, the platform can adapt to the change more efficiently. This property file enables multiple sensors to be linked to a mobile device and to transmit the sensor data over a single wireless link to the u-health server.

When hospitals and insurance companies are engaged with the mobile u-health service scenario described in Section 4, the u-health service scenario needs to be extended. Such kind of environmental change circumventing u-health services may be frequent in real situations. Since u-heath services are defined in the form of processes using the BPMT tool in our platform, they can adapt to such changes more efficiently by adding new service components and/or by replacing some of the service components with alternative ones.

### 7.6 Interoperability

One of important criteria for designing the mobile u-health service platform is interoperability. BPMS is usually equipped with facilities for supporting interoperability. Since our platform is based on BPMS, the facilities of BPMS for interoperability can be shared in the mobile u-health service platform. The remote applications and systems can be integrated with u-health services in our platform without any extra work. The Web Services API for BPMS and the Web portal provide an easy way of exchanging information between processes.

## 8 CONCLUSIONS

In this paper, we have identified several core components of the u-health service scenario process, and described the overall architecture of the mobile u-health platform. We have also developed essential functions and facilities that allow service developers to effectively use the core components to develop various mobile u-health services with less effort.

Our mobile u-health service platform is very unique in that it adopts BPMS as its underlying platform, and u-health services are designed as service processes. The standard u-health service process provides a guideline to u-health service developers. They can specialize and/or extend the service process template to develop their own u-health services. Six design goals are identified for the mobile u-health platform, and we have tried to achieve them in our BPMS-based u-health service platform.

One of the lessons that we learned while working with the mobile environment is that different trade-offs need to be made for different circumstances. For example, we need to consider resource limitations on mobile devices, communication bandwidth, and constraints on user interfaces to make a trade-off between different quality of services for different environments and different user groups.

There are also some pending works to be done to make the platform more secure and reliable. We are currently investigating how to support the features of managing personal healthcare data securely, and enhancing the performance by compressing messages exchanged between mobile devices and the u-health server.

## REFERENCES

D. Konstantas, R. Bults, A. Van Halteren , K. Wac, V. Jones, I. Widya, R. Herzog, B. Streimelweger, “Mobile Health Care: Towards a commercialization of research results”, In proceedings of 1st European Conference on eHealth - ECEH06 -Fribourg, Switzerland, pp.12 – 13, October 2006.

Pappas, C. Coscia, E. Dodero, G. Gianuzzi, V. Earney, M., “A Mobile E-Health System Based on Workflow Automation Tools”, Computer-Based Medical Systems. Proceedings of the 15th IEEE Symposium on pp.271 – 276, June 2002.

Broens, T.H.F., van Halteren, A.T., van Sinderen, M.J., Wac, K.E. “Towards an application framework for context-aware m-health applications”, In: EUNICE 2005 "Networked Applications". 11th open European Summer School, pp.6-8 July 2005.

N. Oliver , F. Flores-Mangas, “MPTrain: a mobile, music and physiology-based personal trainer”, ACM International Conference Proceeding Series; Vol.159, pp.21 – 28, 2006.

E. Jovanov, D. Raskovicl, A. 0. Lords, P. Cox, R. Adharni, F. Andrasik, "Stress monitoring Using a Distributed Wireless Intelligent Sensor System“, in IEEE Engineering in Medicine and Biology Magazine, pp. 49-55, May/June 2003.