An Integrated Healthcare System for Personalized Chronic Disease Care in Home–Hospital Environments

Sangjin Jeong, Chan-Hyun Youn, *Member, IEEE*, Eun Bo Shim, Moonjung Kim, Young Min Cho, and Limei Peng

***Abstract*—Facing the increasing demands and challenges in the area of chronic disease care, various studies on the healthcare system which can, whenever and wherever, extract and process patient data have been conducted. Chronic diseases are the long-term diseases and require the processes of the real-time monitoring, multidimensional quantitative analysis, and the classification of patients' diagnostic information. A healthcare system for chronic diseases is characterized as an at-hospital and at-home service according to a targeted environment. Both services basically aim to provide patients with accurate diagnoses of disease by monitoring a variety of physical states with a number of monitoring methods, but there are differences between home and hospital environments, and the different characteristics should be considered in order to provide more accurate diagnoses for patients, especially, patients having chronic diseases. In this paper, we propose a patient status classification method for effectively identifying and classifying chronic diseases and show the validity of the proposed method. Furthermore, we present a new healthcare system architecture that integrates the at-home and at-hospital environment and discuss the applicability of the architecture using practical target services.**

***Index Terms*—Chronic disease, electrocardiography, enterprise system, integrated healthcare system, personalized healthcare system.**

Manuscript received August 18, 2011; revised January 12, 2012 and February 18, 2012; accepted March 8, 2012. Date of publication March 14, 2012; date of current version July 5, 2012. This work was supported by research and development (R&D) programs by the Ministry of Education Science and Technology/National Research Foundation under Grant 2011-0020522, MKE/KEIT(10039260), MKE/KEIT(10040231), and NRL(ROA-2008-000-20127-0).

S. Jeong is with the Department of Information and Communications Engineering, Korea Advanced Institute of Science and Technology, Daejeon 305-701, Korea, and also with the Standards Research Center, Electronics and Telecommunications Research Institute, Daejeon 305-700, Korea (e-mail: sjjeong@kaist.ac.kr; sjjeong@etri.re.kr).

C.-H. Youn is with the Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Daejeon 305-701, Korea, and also with the Grid Middleware Research Center, Korea Advanced Institute of Science and Technology, Daejeon 305-701, Korea (e-mail: chyoun@kaist.ac.kr).

E. B. Shim is with the Department of Mechanical and Biomedical Engineering, Kangwon National University, Chuncheon 700-701, Korea (e-mail: ebshim@kangwon.ac.kr).

M. Kim is with the Mobile Communication Business Division, LG Electronics, Seoul 150-721, Korea (e-mail: lzbth.mj@gmail.com).

Y. M. Cho is with the Seoul National University College of Medicine, Seoul 110-744, Korea (e-mail: ymchomd@snu.ac.kr).

L. Peng is with the School of Electronic and Information Engineering, Soochow University, Suzhou 215006, China (e-mail: auroraplm@suda.edu.cn).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TITB.2012.2190989

I. Introduction

CHRONIC diseases are increasingly an important concern in e-healthcare systems throughout the world. For example, it is forecasted that clinical expenses for chronic diseases in the U.S. will be 80% of total medical costs and that more than 150 million people may suffer from chronic diseases in 2020 [1]. In response to this challenge, many studies have reported various technical e-health service systems in patient-care monitoring utilizing sensor networks and medical services recently. Particularly, the development of e-health technologies such as mobile computing using dynamic software adaptation techniques [2] or new networking technologies has seen the important elements of chronic conditions based on sensors become a primary issue. In other words, through mobile devices, subcompact sensors, and wireless networks, a health examination is executed and can transmit in real time a patient's physical data to a medical center. Therefore, these systems enable out-of-hospital health monitoring.

Health monitoring in out-of-hospital conditions, especially in the home environment, has drawn the attention of healthcare researchers and developers for a long time. The continuous monitoring of physiological data such as the heart rate or ECG signals in daily life is important for managing chronic diseases such as heart disease [3], [4]. Sensors and measurement devices for health monitoring at home have limited capability for accurate analyses of measured physiological data, and the analysis processes are performed by predefined methods in the devices [5]. Furthermore, it is not easy for a patient to understand the analysis results fully due to a lack of medical knowledge. Thus, a healthcare system should support a collaboration environment among physicians and patients, and provide easy and simple interface for patients.

From a medical service point of view, in order to provide better quality healthcare service for chronic diseases, the following limitations need to be overcome. Patients need a long treatment period with continuous monitoring care. Their condition sometimes may change or worsen unexpectedly. Yet, few existing medical systems provide any alarm about the status of a chronic patient. The usual medical examination processes for disease detection are complicated. Often coping with multiple conditions, chronic disease patients may want to meet multiple physicians at different care sites, but this increases the possibility of risks of errors and poor care coordination. The percentage of reported errors at least doubles among patients seeing four or more physicians compared to those seeing only one or two.

1089-7771/$31.00 © 2012 IEEE

Thus, medical systems should generate reliable outcomes for patients with complex chronic conditions [6]. These challenges encourage the improvement of the quality of healthcare systems in terms of hospital demographic factors, clinical technology, information technology, clinical quality, process quality, hospital financial performance [7], [8], the ease of the access to healthcare and healthcare information, and the reduction of the cost of the delivery of healthcare [9], [10]. Regarding chronic diseases, Epping-Jordan *et al.* founded that when patients with chronic conditions receive effective health management within an integrated system, with self-treatment support and regular follow-up, they do better. Thus, healthcare systems need to be prepared to adapt to changing situations, new information, and unforeseen events [11]. Therefore, it is important work to allow chronic patients to manage their own conditions these days, and healthcare systems are required to assist patients' self-management of their chronic condition by delivering more precise information and suggesting suitable disease management methods [12].

In the following sections, a description of the proposed patient status classification method (PSCM) for chronic disease care is presented, along with its related chronic disease identification procedures. Furthermore, the proposed architecture of an integrated healthcare system is described while emphasizing the service scenario of the system. In addition, several personalized services for patient-specific chronic disease care are presented, aiming to illustrate the applicability of the proposed system to chronic disease patients. Finally, the evaluation of the system and open issues are discussed.

II. Novel PSCM for Chronic Disease Identification

A. *Conceptual Framework of a Healthcare System for Chronic Disease Care*

Conventional healthcare systems have focused on providing specific target services only. However, achievements in various information and communication technologies have enabled much research on personalized healthcare systems for the at-home environment. However, the research thus far has mostly focused on patients' medications for the treatment of chronic disease, e.g., to deliver the right treatment, to the right patient, at the right dose, and at the right time [13], [14]. Healthcare services, such as health monitoring services, medical consultations, and others, need to be personalized based on the context of the patients' profiles. For the efficient provision of personalized healthcare services, it is necessary to identify patients' health statuses accurately, especially for those with chronic diseases, and to distribute the health status to hospital staff using an order communication system (OCS) [15]. Also, a method of efficiently managing hospital equipment and staff in order to reduce costs and improve the service quality including community hospitals' performance and capacity management is another important challenge [16]–[18].

The conceptual framework of the healthcare system for chronic disease is depicted in Fig. 1. The healthcare system for chronic disease is characterized in terms of at-hospital and at-home service according to the targeted environment. Both services aim to provide patients with accurate diagnoses of diseases by monitoring a variety of physical states with a number of monitoring methods. For example, a patient can be examined using many types of medical equipment and tests at the hospital, such as X-rays, computed tomography (CT), multichannel ECG, blood tests, MRI, and others, whereas the patient may be examined with a very limited range of equipment or medical tests at home due to the price of portable medical equipment for the home, the difficulty in operating the medical equipment, or for other reasons. Therefore, extending health monitoring from the hospital to the home environment should consider different monitoring characteristics from those at the hospital [14].

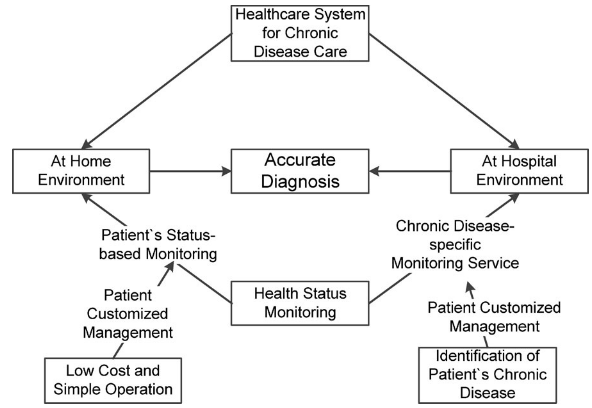


Fig. 1. Conceptual framework of the integrated healthcare system for chronic disease care.

The main objective of at-hospital health status monitoring for patients with a chronic disease is how to provide chronic disease-specific monitoring services, as the criteria and methodology for health monitoring may vary depending on the chronic disease of the patient. For example, the measurement result of a blood pressure test can be interpreted differently based on the patient's status, i.e., whether the patient has diabetes or not. Therefore, it is important to identify the patient's chronic disease accurately and to take disease-specific characteristics into account in at-hospital service processes.

On the other hand, one of the goals of at-home health status monitoring is to provide a simple way to monitor health status at a low cost and with low operational overheads [19]. Assuming that two patients are monitored for the possibility of heart disease using ECG equipment at home and that Patient 1 has a history of heart attack whereas Patient 2 has no history of heart attack, in such a case, it is necessary to monitor and analyze Patient 1's ECG signal carefully, and Patient 1 may need to use ECG equipment with complex functionalities and a high price. However, Patient 2 may use simple ECG equipment that provides a basic analysis of the ECG signal. Thus, it is necessary to provide the patient's status based on health monitoring in order to reduce the cost and overhead of the at-home service.

Therefore, by considering the different characteristics of the hospital and home environments, more accurate diagnoses can be made.

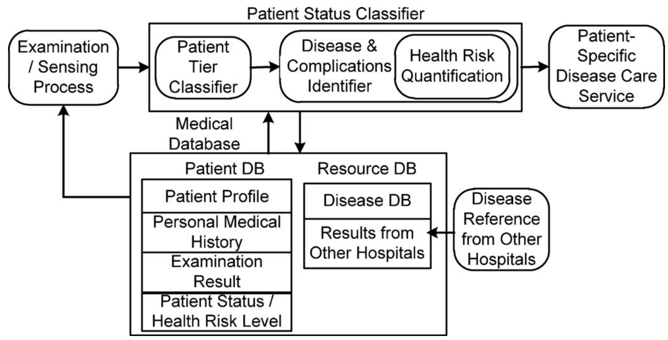


Fig. 2. Procedure of patient-specific chronic disease care based on the PSCM.

B. Functional Architecture of PSCM

For an accurate identification of patients' chronic diseases, we propose the PSCM based on patients' status classification information. The proposed PSCM requires medical information to be stored in a patient medical database. Fig. 2 shows the functional architecture for identifying patient-specific chronic diseases based on PSCM. In the figure, the patient status classifier accesses the medical database and executes an examination process in order to generate chronic disease-specific care rules for a patient. Because accessing the medical database is strictly restricted, we assume that a prior contract for accessing the database is established at this point.

The PSCM is a part of the set of medical decision support tools that allows unified access to a wide variety of patient information and aids in the diagnoses of patients' diseases with filtered medical data. Several studies have been performed to model medical treatment effects and infectious diseases [20]. Our PSCM for identifying chronic disease focuses on accurately identifying patients' chronic diseases and quantifying the risks of the identified chronic diseases. The patient status classifier consists of two subcomponents: the examination and patient tier classifier, and the disease and complications identifier.

C. Examination and Patient Tier Classifier

When a patient receives medical examinations at multiple hospitals, it is not easy to manage and integrate the medical examination results of the patient because the examination results may vary due to many reasons, such as differences in the accuracy of the examination equipment and human error in reading the results. Thus, we introduce classification thresholds for classifying the examination results of a patient. If we define thresholds for the classification of the actual inspection ratio which is expressed as the ratio of the personal examination result set to the results in the disease database, it is possible to determine the ranges of the normal ratio. It is also possible to specify ranges for an abnormal ratio by comparing the ranges of chronic disease patients to the ranges of normal people. We identified the area where the thresholds can be extracted from the boundary of medical information representing abnormality. As shown in Fig. 3, we classified the patients into five tiers according to the threshold *T(i)*, where $1 \leq i \leq 5$. We empirically adjusted the thresholds so that the test results of the patients can consistently fall into the same patient tier. If a given set of patients who have similar symptoms is classified into the same patient tier, e.g., TIER(4) by applying *T*(4), we can determine the thresholds of ranges for TIER(4).

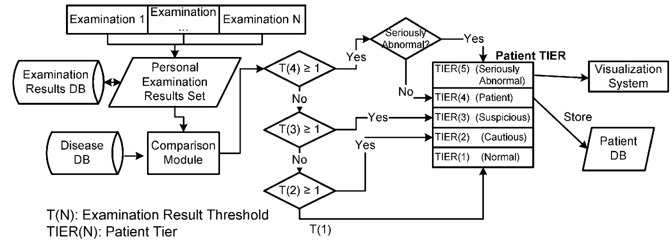


Fig. 3. Classification of a patient's tier using the disease database.

TABLE I
SAMPLE PERSONAL DISEASE SET

Patient ID	Patient TIER	Examination	Test	Figure	Result
2	*TIER(4)*	Diabetes mellitus test	HbA1c	over 8% (over 212 mg/dL)	*T(4)*

TABLE II
EXAMPLE OF PATIENT TIERS FOR MEDICAL TEST RESULTS

Examination	Test	*T(1)*	*T(2)*	*T(3)*	*T(4)*	*T(5)*
Diabetes mellitus test	HbA1c(1)	Under 5% (under 97 mg/dL)	5~6% (97~154mg/dL)	6~7% (154~183mg/dL)	Over 8% (over 212 mg/dL)	Seriously abnormal

(1) HbA1c (Plasma Glucose).

If a patient is classified into TIER(5), the visualization system will send a warning notice to the physician's device immediately. In other cases, the classification results including the ranges and thresholds are stored in the patient database. Samples of the personal disease set and medical test results are summarized in Tables I and II, respectively.

D. Disease and Complications Identifier

A patient of TIER(4) who has a chronic disease according to the results of the patient tier classifier is analyzed in the disease and complications identifier as to whether the patient has any sickness. The first step of this identifier is to diagnose the patient using an approved template and chart for the state. In this step, the disease and complications identifier helps the physician diagnose and treat the patient by providing the calculation results of a comparison between the status of a normal person, i.e., TIER(1) and the disease database template.

Then, the patient's examination results are compared with the disease database. We assume that the disease templates are stored in the Disease database. In the second process, a radar priority calculation using surface measure of overall performance (SMOP) theory [21] is applied to identify the disease. Finally, the identified results are sent to the patient-specific disease care module, as shown in Fig. 4.

During the procedures for the identification of the disease and complication tier, we need to measure the statistical data accurately. We use the SMOP method by Schütz [21] to generate a

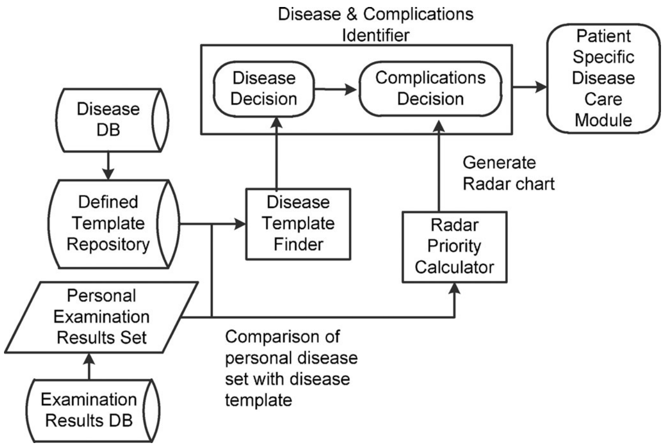


Fig. 4. Disease and complications identifier for the patient status calculation.

Patient 2 Profile	
Gender	Male
Age	45
Race	Asian
Family History	Y
Therapy Experience	5 Years

Examination Tier	TIER(4)	
Questionnaire	Smoking	
Blood Pressure	Hypertension	140/90mmHg
Diabetes mellitus	Fasting Glucose	100 ~ 125 mg/dl
	Average Glucose	200 mg/dl
	HbA1c	8%
Lipid	LDL-cholesterol	160 ~ 189 mg/dl
	Total-cholesterol	245 mg/dl
	HDL-cholesterol	62 mg/dl
	Triglycerides	510 mg/dl
BMI (Body Mass Index)		30 kg/m^2

- Nutrition check
  - Total Energy requirement state
  - Carbohydrate/fat/protein ratio
- Diet check
  - Diet Plan
  - Insulin dosage regimen
  - Manager list
- Exercise check
- Rounds – 2hours

- Patient Character
  - Disease Decision history (Order record)
  - Complications status
  - Health Risk Level
- Physician's comments
  - Other hospital experience list
  - Physician 1
  - Physician 2

Fig. 5. Basic examination results of a person.

radar chart for identifying the disease. Because the data of the disease set are normalized by the different criteria in the different ranges from $T(1)$ to $T(5)$, the statistical classifications fall within five tiers. There are several advantages when using a radar chart. 1) It provides a self-evident and synoptic description of multiple performance measures; 2) makes the trade-offs between performance measures visible; and 3) provides a synthetic measure of the overall performance and delivers first-hand monitoring indicators through comparisons of performance measures over time [22]. According to the theory [21], SMOP can be expressed as follows:

$$\text{SMOP} = \frac{(P_1 \times P_2 + P_2 \times P_3 + \cdots + P_{n-1} \times P_n + P_n \times P_1) \times \sin(360/N)}{2} \tag{1}$$

where $0 \leq P_n \leq 1$ and $n = 1, 2, \ldots, N$.

N denotes the number of medical tests for a patient examined.

P_n represents in which range the medical test N falls. In this section, we defined five ranges, from $T(1)$ to $T(5)$; thus, the value of P_i is determined as follows:

$$P_i = \begin{cases} 0.2, \text{ if } i\text{th test result is within } T(1) \\ 0.4, \text{ if } i\text{th test result is within } T(2) \\ 0.6, \text{ if } i\text{th test result is within } T(3) \\ 0.8, \text{ if } i\text{th test result is within } T(4) \\ 1.0, \text{ if } i\text{th test result is within } T(5). \end{cases} \tag{2}$$

MAX_SMOP is the upper bound of SMOP and is calculated by setting P_n to 1.0 where $n = 1, 2, \ldots, N$, so

$$\text{MAX\_SMOP} = \frac{N \times \sin(360/N)}{2}. \tag{3}$$

When we define the patient disease complication C_{patient}, the percentage of patient disease compliance is obtained by the ratio of SMOP and MAX_SMOP as

$$C_{\text{patient}}(\%) = \frac{\text{SMOP}}{\text{MAX\_SMOP}} \times 100. \tag{4}$$

E. Validation of the Proposed PSCM

To verify the validity of the proposed PSCM, we consider diabetes here as a chronic disease. It is known that diabetes mellitus is one of the major chronic diseases at present. The increase in diabetes mellitus represents a public health crisis driven mainly by the cardiovascular risk associated with diabetes: stroke and heart disease account for approximately 65% of deaths in people with diabetes [23], [24]. Therefore, we verified whether our PSCM can identify and classify the status of diabetes disease patients using sample patient data. Then, in the following section, we propose the integrated healthcare system architecture suitable for chronic disease care services and personalized user interfaces based on the proposed PSCM.

For validation of the proposed PSCM, we used sample patient data (Patient 2). The medical examination results are depicted in Fig. 5. The sample data contain the patient's profile, information for corresponding physicians, health management status data and basic examination results, and other pertinent information. The basic medical examination consists of twelve criteria from the Korean Basic Physical Examination. The elements of the examination are based on daily examination recommendations by the Lifetime Health Maintenance Program for Koreans [25]. After the basic examination, Patient 2 was classified as a chronic disease patient. The patient was then examined with 12 medical tests in order to determine the patient tier and to identify the disease and complications using PSCM. The summary results of the 12 tests are shown in the table in Fig. 6. By utilizing the table, we can determine each value of P_i in (2) and generate a radar chart for visualization. According to (1)–(4), SMOP, MAX_SMOP, and $C_{\text{patient}}(\%)$ are calculated as follows.

1) SMOP $= 0.67$.
2) MAX_SMOP $= 3.0$.
3) $C_{\text{patient}}(\%) = 0.22$.

Because the analysis results showed that there is a correlation between $C_{\text{patient}}(\%)$ and the patient's health risk, we can indirectly estimate the health risk of the patient using the value of $C_{\text{patient}}(\%)$.

	T1	T2	T3	T4	T5
BMI				O	
Sight / Hearing	O				
Waist				O	
Blood Pressure				O	
X-ray	O				
Diabetes Mellitus				O	
Lipid Test (Cholesterol)				O	
Complete Blood Cell Count (CBC)		O			
Renal Function	O				
Liver Function		O			
Oral Cavity	O				
KDSQ-P[(1)]	O				

[(1)] Korean Dementia Screening Questionnaire (KDSQ) - P

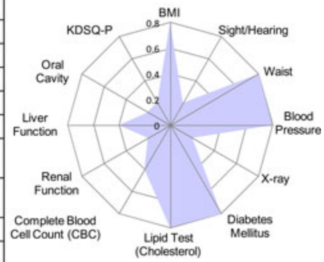


Fig. 6. Radar chart showing the identified patient tiers of 12 medical tests.

III. Integrated Healthcare System for Personalized Chronic Disease Care

A. Architecture of the Integrated Healthcare System

An integrated healthcare system that enables health monitoring and disease management in the home environment has been a major research area for healthcare researchers. Integrated healthcare systems mainly focus on monitoring patients' health status, detecting and managing potential diseases in the early stage, and managing health problems in daily life [26]. Extending health monitoring from the hospital to the home environment should not be seen as a replication of the same monitoring procedures and methods of the home environment, because the home environment has characteristics that are very different from those of the hospital in terms of medical facility, human resources, the medical knowledge of operator, and other factors. Thus, the approach for simply building the same monitoring architecture as the hospital will dramatically increase the time and human resources necessary for healthcare services delivery. It may also be unacceptable for patients due to its obtrusive and stressing nature. Within the scope of continuity of healthcare, the need to move beyond passive monitoring to efficient mechanisms for personalized healthcare is becoming more and more evident [14]. As was discussed in Section II, one of the emerging requirements for a healthcare system is to provide various health monitoring and disease detection services in the context of each user's characteristics. The key goal of the healthcare system at a hospital is to detect anomalies in patients' physiological parameters as accurately as possible and to make diagnoses of potential diseases based on the detected anomalies, whereas the objective of home healthcare is to provide simple and easy methods for monitoring patients' health status while they carry out the activities of daily life [19].

In order to overcome the challenges of developing healthcare systems for home environments, it is desirable to support industrial information integration methods such as service-oriented architecture and multitenancy patterns in chronic disease services so that patient-specific healthcare services can easily be integrated into the healthcare system [27], [28]. The service-oriented architecture is an appropriate solution for improving integrated healthcare systems, as it is known that the service-oriented architecture can provide a unified platform for managing various services, such as data federation, temporal order filtering, and image processing. Also, a service-oriented architecture can offer a reduction in the system complexity, an increase of service extensibility, and good replaceability [29]. Therefore, we designed the architecture of our proposed healthcare system based on the service-oriented architecture (see Fig. 7). Because the proposed architecture follows the general approach for developing integrated medical information systems in the literature [30], [31], we briefly describe the major components of the system and provide a detailed description of chronic disease care services in the following sections. The system developed in this research consists of three major components: a personalized user interface, an integrated healthcare server, and chronic disease care services.

Personalized User Interface: Our system provides separate user interfaces according to the user types, i.e., the patient and the physician. The patient's interface displays an abstract and simplified view of the health monitoring results, whereas the physician's interface shows detailed information, such as patient's profile and medical history. User interfaces communicate with the integrated healthcare server by exchanging extensible markup language (XML)-based messages. The simple object access protocol was used as the XML-based message binding protocol.

Integrated Healthcare Server: This component is responsible for the main operation of the system. It consists of six subcomponents.

1) *Web Interface Module:* This includes the web application server (WAS), web server, UI repository, and heart disease analysis results module. WAS is used for supporting the web interface of the patient and physician interfaces. If the user interface is a mobile environment, an appropriate application interface for a mobile device, such as a smart phone, is selected from the UI repository and provided.
2) *Service Registry (UDDI):* Various healthcare services developed by the service-oriented architecture are registered in the service registry. The service registry provides naming abilities and translations of names to the web service definition language. A more detailed description of the operational procedures of the chronic disease care services is presented in the following sections. Among the registered healthcare services, appropriate services for patients' characteristics, such as the chronic disease and the service environment, are executed to provide personalized healthcare service.
3) *Communication and Monitoring Module:* This module takes care of communication among the healthcare service participants, such as patients, physicians, and informants, and collects various types of measured data of patients on either a real-time or a nonreal-time basis. The collected data are then transferred to the decision support tool.
4) *Decision Support Tool:* This identifies patients' chronic diseases and their status using PSCM as proposed in Section II.
5) *Patient-Specific Disease Care Service Module:* This component receives information about patients, including the patient profile and chronic disease, and analyzes patients'

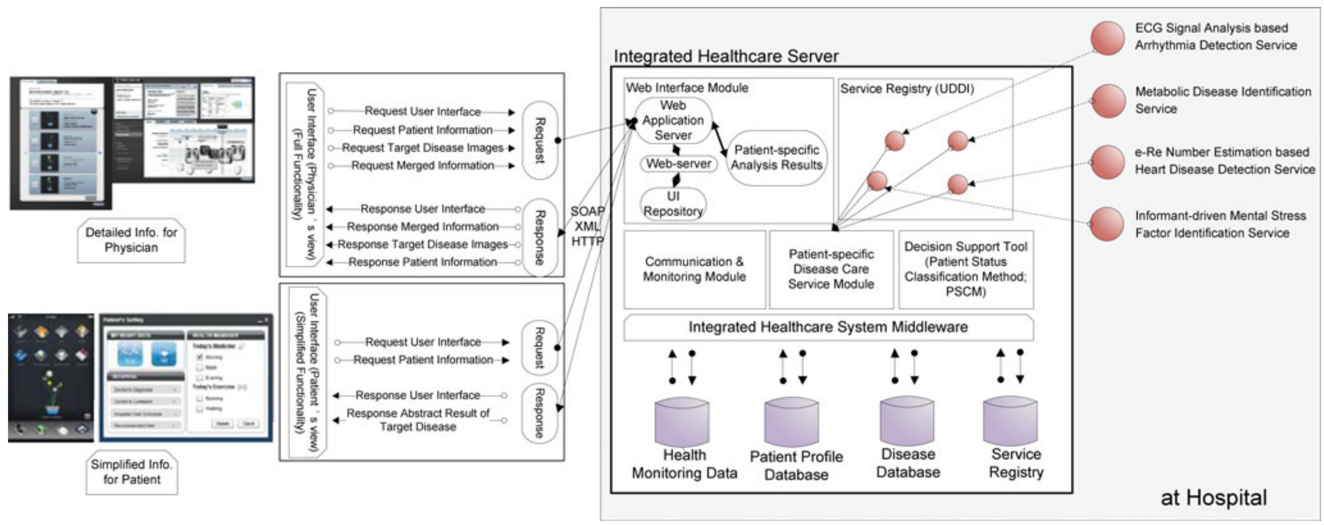


Fig. 7. Architecture of the integrated healthcare system.

measured health data. In order to perform the analysis, appropriate healthcare services registered in the service registry are utilized. The analyzed results are moved to the web interface module and are finally delivered to the user interfaces of the patients and physicians.

6) *Integrated Healthcare System Middleware:* Each type of module in the server can communicate with healthcare databases using middleware.

Chronic Disease Care Services: Currently, our system provides four types of chronic disease care services: 1) the mental stress factor identification service; 2) the *e-Re* number-estimation-based heart disease detection service, 3) the metabolic disease identification service; and 4) the ECG signal-analysis-based arrhythmia detection service. The references of the services are registered in the service registry. In the future, our system may be extended to collaborate with other emerging disease care systems such as analyzing system for HIV transmission and subsequent progression to AIDS or bidirectional human–machine interface system for paralyzed patients [32], [33].

B. Service Scenario for Patient-Specific Chronic Disease Care at Home–Hospital

The service scenario for personalized chronic disease care is shown in Fig. 8. When a patient comes to the hospital, the patient receives several medical examinations in order to check the patient's health status and to check for possible chronic diseases. If a chronic disease is detected, a physician verifies the detection results as to whether or not they are valid. The patient-specific disease care services are then uploaded to integrated healthcare system and the system interacts with the physician. When the patient goes back home and monitors their health status using home medical equipment, the measured data are transferred to an informant at a remote site. The informant monitors the patient's health data and periodically stores the data in the medical database in the hospital. If an anomaly is detected in the patient's health data, the informant reports the anomaly to the physician. Then, the physician examines the patient's health data and makes a diagnosis. If necessary, the patient goes to the hospital for further examination.

C. Service Levels for Patient-Status-Based Healthcare Services

In the proposed integrated healthcare system, we classify at-home services into three levels according to the target patients: serious patients, potential patients, and normal patients. Each patient class is determined based on the proposed PSCM. The serious patent service class is mapped with the TIER(4) patient group based on the patient tier classifier introduced in Section II. The potential patient service class is mapped with the TIER(3) and TIER(2) patient groups, and the normal service class is mapped with the TIER(1) patient group. The TIER(5) patient group is not mapped into any service class because patients in TIER(5) need intensive care in the hospital. Therefore, it will not be possible to use a healthcare system at home.

Table III lists the differences in the ECG monitoring services for heart disease detection. The serious patient service is the service level at which the patient can receive all diagnostic services. The potential patient service is the service level for a patient who can be classified as a potential patient who does not have any noticeable heart disease symptoms but wants to receive a diagnosis of their disease status. The normal service is the service level for a person who wants to check the basic status of their heart. Each service level has a different set of at-home healthcare services, as shown in the second row (basic diagnosis service) of the table.

D. Chronic Disease Care Service: Informant-Driven Mental Stress Factor Identification Service

The mental stress level and heart disease, such as tachycardia or bradycardia, demand close patient observation and constant patient care. In order to manage such patients, a physician needs to know the heart rate and stress response inventory (SRI) scores. Then, the physician may investigate the physiological relationships between heart rate and each SRI score to identify

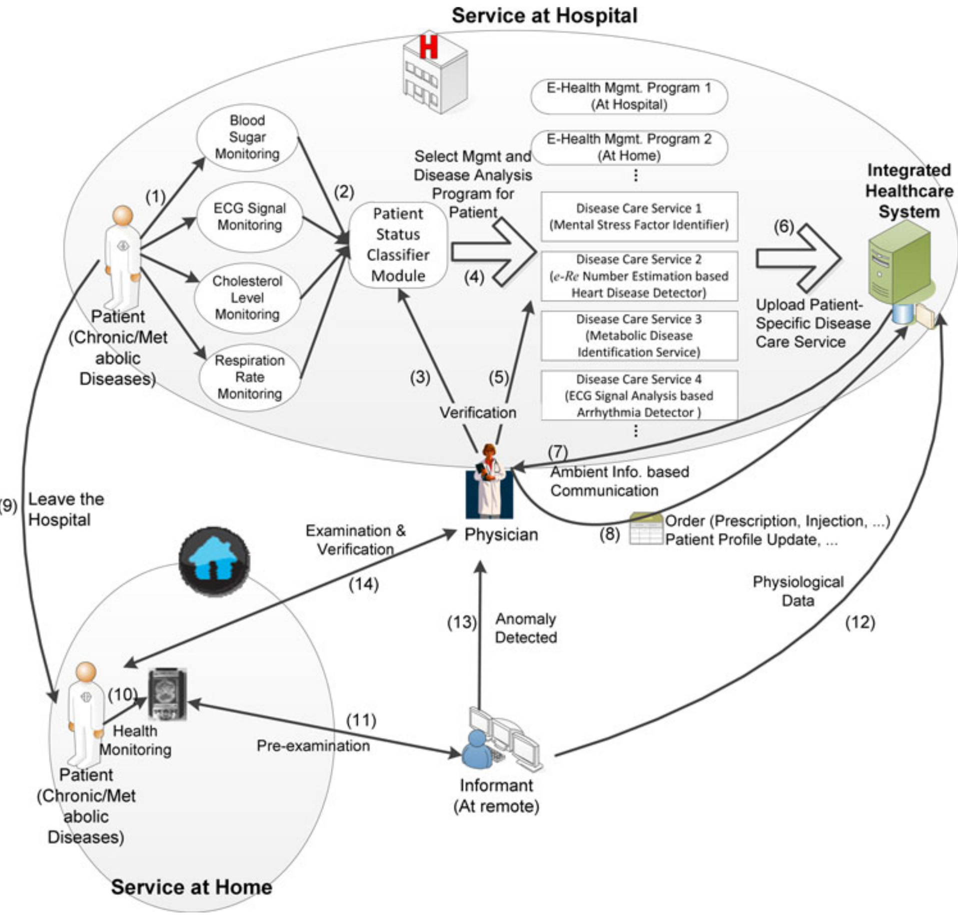


Fig. 8. Service flow for personalized chronic disease care for the home–hospital.

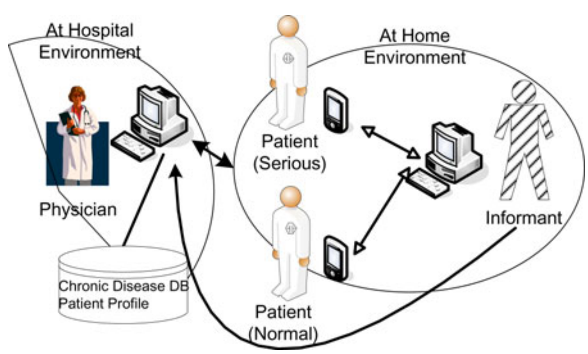


Fig. 9. Informant-driven mental stress factor identification service.

mental stress factors that may induce heart rate changes. Several studies have been performed to identify the relationship between the mental stress factor and heart rate changes [34]–[36]. We have adopted the stress factor identification method presented in [35] and [36] to the at-home–hospital environment so that physicians can investigate the relationship between mental stress factors and chronic disease, as shown in Fig. 9. The stress factor identification method is based on multiple linear regression models (MLRM) between heart rates and each SRI score.

Twenty two SRI questions (Q_{SRI}) are transmitted periodically from the informant to the patient's mobile device. The patient replies to the SRI questions and n ECG signals are transmitted from the patient through the mobile device to the informant at the same time. The transmitted SRI responses and ECG signals are saved in the informant's database. Then, if the patient's heart rate changes, the informant notifies the stress heart information system and the physician to identify the mental stress factors (Q_{MLRM}) with MLRM (see Fig. 10) [36].

E. Chronic Disease Care Service: e-Re Number-Estimation-Based Heart Disease Detection Service

Cardiac arrhythmia is life-threatening medical emergency that can result in cardiac arrest and sudden death. According to a medical report by the American Heart Association 2010, approximately 55% of heart disease patients die due to arrhythmia. Serious cases of arrhythmia, such as ventricular tachycardia or fibrillation, are mostly induced by vortex-like reentrant electric waves in cardiac tissue. In this research, we have integrated a new service for arrhythmia management based on a biomarker index of cardiac arrhythmia in our integrated healthcare system. The index, termed "*e-Re*," was introduced in our previous paper. It is partially based on the Reynolds number of the fluid dynamics [37]. The index and Reynolds number are similar in form, physical meaning, and function. It was shown that electrical

TABLE III
THREE SERVICE LEVELS IN AT-HOME HEALTHCARE SERVICES

Phase	Service Level		
	Serious Patient *TIER(4)*	Potential Patient *TIER(3)/TIER(2)*	Normal *TIER(1)*
(Basic) Diagnosis Service	Patient Profile (S1) Disease Profile (S2) (Local) ECG Profile (S3) Long-Term ECG Profile (S4) HRV Feature Generation (S5) Poincare Map Generation (S6) Poincare Feature Generation (S7) AF Estimation (S8) Bradycardia Estimation (S9) Tachycardia Estimation (S10) Physician Comments (S11)	Patient Profile (S1) Disease Profile (S2) (Local) ECG Profile (S3) HRV Feature Generation (S5) Bradycardia Estimation (S9) Tachycardia Estimation (S10) Physician Comments (S11)	Patient Profile (S1) Disease Profile (S2) (Local) ECG Profile (S3) HRV Feature Generation (S5)
Advanced Diagnosis Service	Virtual Heart Simulation (S12) Collaborator's Comments (S13)	-	-
Result Report	Cell-Phone (S14) Web-Portal (S15) E-Mail (S16)	Web-Portal (S14) E-Mail (S15)	Web-Portal (S14) E-Mail (S15)
Experienc es	Physician With More than 10 years of experience	Physician With Less than 10 years of experience	Physician With Less than 10 years of experience
Duration	30 Days	7 Days	1 Day
Period	Every 1 min	Every 60 min	Every 60 min
Quality	Within 1 min High Stable Resources High Reliability (99%) High Security	Within 10 min Middle Stable Resources Middle Reliability (99%) Middle Security	Within 60 min Low Stable Resources Low Reliability (99%) Low Security
Cost	10 Unit Cost	5 Unit Cost	2 Unit Cost

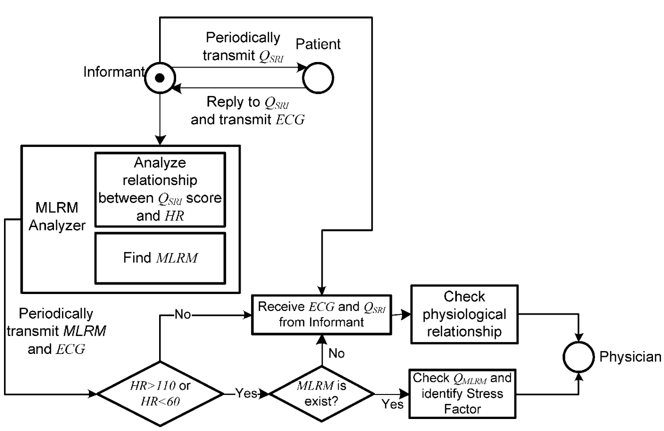


Fig. 10. Operational procedure for the mental stress factor identification service.

wave patterns in cardiac tissue can be classified according to the magnitude of the index, just as fluid flow patterns are determined by Reynolds numbers in fluid dynamics. The *e-Re* number can categorize reentrant arrhythmia in the human heart. Specifically, if the cardiac electrophysiological condition of the *e-Re* number exceeds a critical threshold value, reentrant tachycardia or fibrillation is easily generated by some abnormal ectopic beat.

The integrated healthcare system can use the *e-Re* number to monitor the arrhythmic risk of patients with real-time ECG signals, as shown in Fig. 11. To calculate the *e-Re* number, some

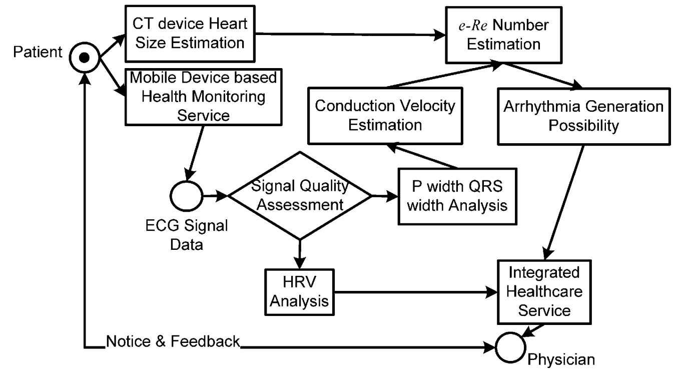


Fig. 11. Operational procedure for the *e-Re* number-estimation-based heart disease detection service.

parameters of the patient, such as the characteristic frequency and length of the patient's heart and electric conduction coefficient of the heart, are required. The characteristic length of the heart is determined by the muscle volume of the left and right ventricles. The muscle volume of the heart can be measured by ultrasound or with a CT device once a year or once every half year, as it does not change easily within short term shorter than one year. The conduction coefficient of the cardiac tissue is estimated from duration of the P wave or the QRS complex, which can easily be measured using an ECG device. The characteristic frequency indicates the heart rate. Therefore, the integrated healthcare system can provide more detailed and specific information about an arrhythmic patient by obtaining the *e-Re* number in addition to the real-time ECG signal. Fig. 11 shows the service flow for the *e-Re* number-estimation-based heart disease detection service.

F. Chronic Disease Care Service: Metabolic Disease Identification Service

Metabolic syndrome is a cluster of symptoms such as diabetes, obesity, hyperlipidemia, and high blood pressure. It was well known that the mitochondria are "the body engine" for energy production, enabling life activity. Their dysfunction can induce metabolic syndrome [5]. According to epidemiologic and clinical observations [38], [39], a decrease in the mitochondrial deoxyribonucleic acid copy number is responsible for type II diabetes mellitus. Thus, it is critical to measure the capability of mitochondria energy production for an early diagnosis of metabolic syndrome or type II diabetes mellitus.

Recently, we have developed a prediction system for metabolic syndrome by adding the information of mitochondria metabolism as measured using nanotechniques [5]. In the study [5], it was shown that mitochondria metabolism could be evaluated by the capability of energy production, which is closely related to the cellular temperature. We also discussed a sensor-integrated system model for metabolic syndrome predictions with a workflow system. This model measures not only the cell temperature variation using an invasive method, but also involves a controlling simulation for metabolic syndrome predictions.

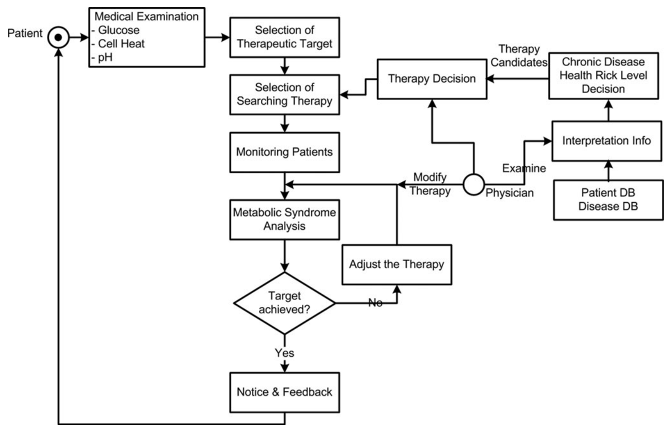


Fig. 12. Operational procedure for the metabolic disease identification service.

To predict metabolic syndrome, we designed a hybrid metabolic syndrome analysis system (see Fig. 12) that has high precision sensor units, a network interface to deliver the analysis results of human cells, annotation data from a public hospital, and metabolic data. Using this system, as shown in Fig. 12, we can evaluate the functionality of human mitochondria and analyze the energy metabolism.

IV. Evaluation and Discussion

A. Implementation Examples of the Integrated Healthcare System

This section presents implementation examples of our integrated healthcare system for personalized chronic disease care. As discussed in Section III, our system supports two types of user interfaces. One interface is for a physician and the other is for a patient. Fig. 13 shows the physician's interface, which provides detailed information about the patient status and physiological data. After the PSCM procedures, a physician can check the status of chronic disease patients through the OCS and with a mobile device with a simplified interface. The OCS provides detailed information such as the patient's profile, the results of the patient's medical tests, and their complication history. It also provides the patient status based on PSCM so that the physician can review the patient's status classification and confirm whether the status is appropriate or not. After the physician's confirmation, the patient status is displayed on the physician's mobile device with a simplified interface. To provide an easy and intuitive recognition of the patient status, we designed an ambient information interface with a mobile widget, termed Physio-Garden. The mobile widget-based interface shows the patient status classification information in real time by communicating with the integrated healthcare server. The interface shows the patient's status as a flower pot, as shown in Fig. 13(a). The key design goal of the widget is to support a more intuitive recognition of the patient's status. We built the widget interface with Adobe Air 1.5 [40] and Java [41]. The patient's status can be represented as follows.

1) Main flower: conditions are in one of five health statuses, which presents the patient TIER as classified by PSCM.

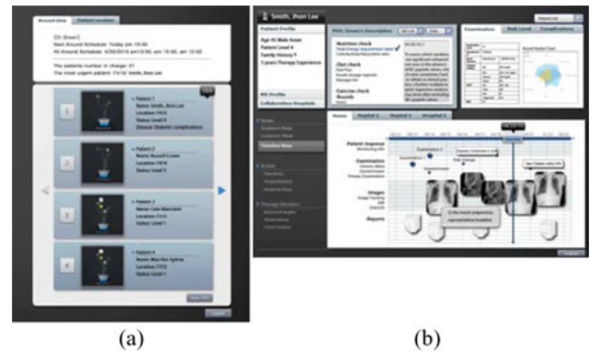


Fig. 13. Detailed information-based interface for the physician. (a) Interface for mobile device. (b) OCS interface.

Fig. 14. Simplified information-based interface for the patient.

2) Butterflies: an alarm for communication among users is given.
3) Pot: an additional care measure for a patient, such as doing exercise and taking medicine, can be managed.

The interface represents the patient's examination results and allows a physician to notice quickly whether or not patient is in an urgent state. Therefore, during their regular local rounds, the physician can quickly check the patient's status while interviewing the patient. In this way, our system can help reduce the physician's overhead and make medical processes related to patient's status monitoring more efficient.

The simplified interface for the patient is depicted in Fig. 14. The patient's interface also supports a mobile widget-based patient status display in order to support intuitive recognition of the patient's health status. Also, the patient's interface provides a self-care function, which manages the patient's medication and exercise, hospital visit schedule, and diet.

In addition, to predict metabolic syndrome, we used a hybrid metabolic syndrome analysis system (see Fig. 15) that had high-precision sensor units interworking with a cybrid system, a network interface to deliver the analysis results of human cells, annotation data from a public hospital, and metabolic data. Using this system, as shown in Fig. 15, we can evaluate the functionality of human mitochondria and analyze the energy metabolism. The prototype system plays a key role in predicting metabolic syndrome estimation services in the integrated healthcare system introduced in Section III.

Given the results shown in Fig. 16, we found that cybrid cells from patients with metabolic syndrome release less heat than those of normal subjects.

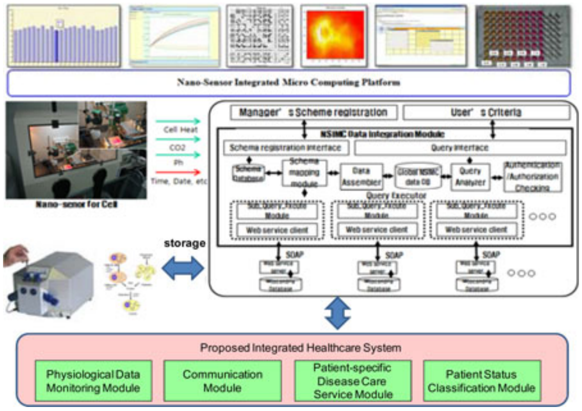
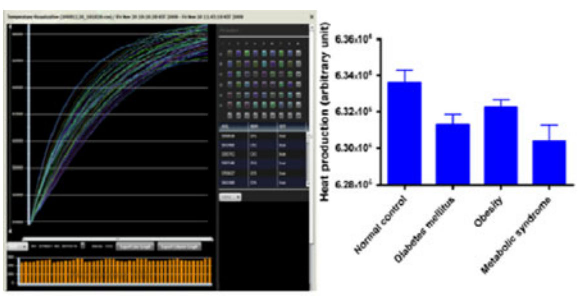


Fig. 15. Measurement system for human cell metabolism (from [5]).



(a) (b)

Fig. 16. Results of cell metabolism measurement and a cybrid test using the metabolic measurement system shown in Fig. 15. (Adopted from [5]). (a) Cell temperature data workflow and its visualization with 48 channels. (b) Comparison of heat production among different cybrid cell lines (normal, diabetes mellitus, obesity, and metabolic syndrome) using the test system shown in Fig. 15.

Through the system application shown in Fig. 16(b), the system user can set up a target correlation of 85%, an evaluation workflow of obesity (weight/height rate over 70% for simplicity), and an analysis workflow of mitochondria heat measurement (e.g., obesity and heat measurement through the parameter controls in the measurement system).

B. Performance Evaluation of the Sample Services in the Integrated Healthcare System

In order to evaluate the proposed integrated healthcare system for chronic disease care, we considered a number of main factors related to the physician's time and, then, calculated how these factors can affect the medical staff's labor burden or their system usability. We utilized methods of calculating primary care in typical physician's activities [42], [43]. Because it is known that a considerable factor enhancing physician productivity is "time spent with the patient" except the physician's practice patterns such as charting, writing notes, and writing prescriptions [44], we define two types of criteria for calculating physician productivity by analyzing the time patterns spent with their patient. First, we investigated the practical medical procedures and time for chronic disease care. Second, we organized the important factors as a time function suitable for our evaluation. Then, among various evaluation methods, we evaluated the workload of the physician over time.

TABLE IV
LIST OF RECOMMENDED SERVICE STEPS

Step	Time/visit (T_{ORG})	Time/visit (T_{PSCM})
Patient Triage	T_{triage}	T_{LC}
Time spent with patient (Examination analysis & Tests record check)	T_{exa}	T_{CI}
Follow-up ordered/ Action control	T_{fol}	T_{PS}

$T_{\rm LC}$: time spent in the patient tier classifier step.
$T_{\rm CI}$: time spent in the complications identifier step.
$T_{\rm PS}$: time spent in the patient-specific disease care step.

In earlier work [42], the authors investigated the distribution of the patient visit time and classified time categories consisting of the patient visit time. Thus, according to the presented time categories, we extracted time functions for the chronic disease patient care process, as follows.

1) A list of recommended service steps.
   a) Time in triage.
   b) Physician's attending time, both the visit time and the medical data analysis time.
   c) Time spent with the medical decision and control action.
2) The frequency of conducting each service.
3) The number of people requiring each service.
4) The time required to administer each service.

These four factors are compared with the annual treatment time available for primary care. In other words, we evaluated how much time can be reduced and compared a diabetic scenario with both types of physician time spent to check all examination results along with the physician time spent while analyzing the essential examination results through PSCM procedures.

Thus, we separated the medical staff's work flow according to the three parts of time shown in Table IV, which is the time to sort patients, to review the medical information of the patients, and to take follow up measures for disease.

In addition, we considered the frequency of examinations, the number of people, and the management time as medical service elements. We excluded the patient waiting time in all steps considering the system's usability to decrease the physician's workload.

Consequently, we can assume that the physician's workloads are proportional to the physician time

$$\text{Workload} \propto \text{Time cost}$$

$$T_{\rm org} = T_{\rm triage} + T_{\rm exa} + T_{\rm fol} \tag{5}$$

$$T_{\rm PSCM} = T_{\rm LC} + T_{\rm CI} + T_{\rm PS} \tag{6}$$

where $T_{\rm org}$ in (5) refers to the total time for a physician to perform all medical procedures in order to make a medical decision. $T_{\rm PSCM}$ implies the total time based on our proposed PSCM-based procedures. $T_{\rm triage}$ is the time spent for the classification step as to whether a client is a patient or not. Finally, $T_{\rm exa}$ is the time required to analyze the results of the examinations and tests or treatments during the physician work-up. This stage includes the time to analyze each patient's medical chart data. After the physician's decision procedure, T_{fol} is related to the time for order processing by physicians or staff members who are in charge of controlling the patient disease.

We assume that the physician's service procedure in this system proceeds through the following steps: 1) monitoring of OCS; 2) history data analyzing; and 3) chronic disease decision making. We also assume T_k as the total number of transactions according to patient *k*. When the physician identifies the chronic diseases of *N* patients, we assume P_k as the total number of processes according to patient *k*. The computing load of the first step for patient *k*, W^k_{process}, is represented as $\sum_{k=1}^{N} T^k_{\text{history}}(P^k_{\text{OCS}})$, where patient *k* represents the number of service patients at *k* = 1, 2, ..., *N*. Let us assume the number of jobs involving either handling data from patients or waiting for a physician's access or in the execution for the patient *k*. Therefore, we can define the operation cost function as follows:

$$C_{\text{OCS}} = (W_{\text{lower}}, W_{\text{process}}, W_{\text{history}}) = C_{\text{ser}}\left\{W_{\text{lower}} \cdot \left(\sum_{k=1}^{N} W^k_{\text{process}} + W_{\text{history}}\right)\right\}. \quad (7)$$

Here, *k* = 1, 2, ..., *N*. *N* is the number of service patients. C_{ser} indicates the unit cost factor. We consider an estimated lower boundary W_{lower} of a physician's workload according to a limited queuing analysis of a job implementation [45].

As previously stated, both T_{org} and T_{PSCM} are the physician's time per service

$$C_{\text{medicare}} = C_{\text{ser}} \cdot W_{\text{lower}} \cdot \sum_{k=1}^{n}\sum_{h=1}^{m}\{(v_k - 1) \cdot f \cdot n \cdot T_{\text{org}} + v_k \cdot f \cdot n \cdot T_{\text{PSCM}}\}. \quad (8)$$

Here, $\sum_{k=1}^{n}$ is the sum of service 1 to *n*, and $\sum_{h=1}^{m}$ is the sum of local hospital's count number 1 to *m* for a physician; v_k is a control number of zero or one; if (v_k −1) is zero, a PSCM model is applied for the patient *k*. This indicates that v_k equals one when patient *k* is a patient with a chronic disease and his classification TIER is over four, as explained in Section II. In addition, *f* is the annual frequency of delivery of the service and *n* is the number of individual patients. C_{medicare} in (8) represents the overall service cost of the proposed medical service system.

In existing medical procedures, physicians or medical staff are required to review all medical data before making a medical decision, which requires time to check and analyze all data. On the other hand, by utilizing the PSCM procedures, physicians have only to check some of the total medical data that show problems. The visualization system using PSCM also assists them as they make decision as it assumes an analysis result about the patient's status. The proposed PSCM architecture provides several functions that may replace some processes of the medical service, such as patient triage or patient priority classification. Therefore, the PSCM can provide more physician time for doctors by reducing the doctor's overhead and improve the service quality of the hospital service.

The results, as shown in Figs. 17 and 18, represent a comparison of the processing time to identify metabolic disease according to different service classes. The horizontal axis represents the number of concurrent processes for patients with a chronic disease which are running in our integrated healthcare system. The vertical axis denotes the elapsed time to finish the execution of the metabolic disease detection service. According to the patient status classification, our system provides three service levels: premium, standard, and basic. As we described in Section III, serious patients are suggested to use the premium service in order to guarantee their quality of service. The standard service level guarantees service quality when the healthcare server is lightly loaded, but the service quality may not be guaranteed when the server load is high. The basic service level is processed by a best effort method.

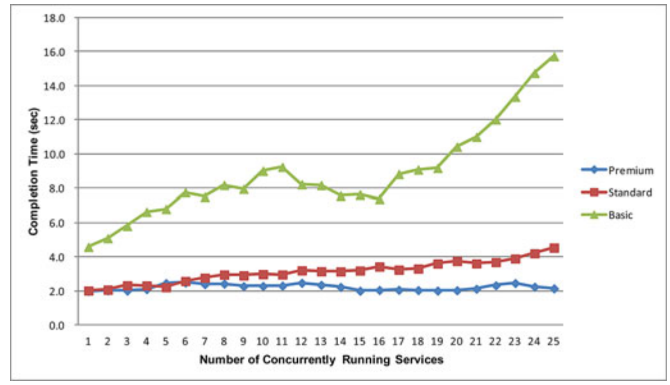


Fig. 17. Processing time to identify metabolic disease in the integrated healthcare system under a heavy sever load.

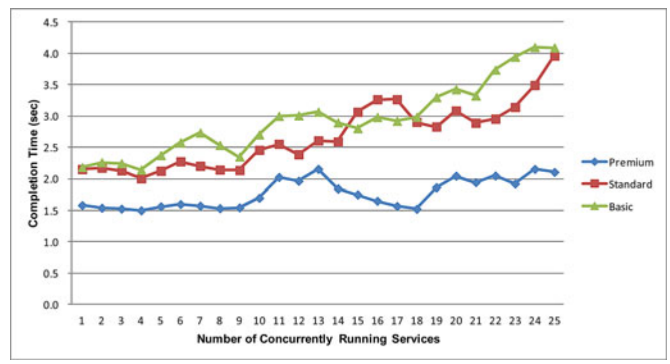


Fig. 18. Processing time to identify metabolic disease in the integrated healthcare system under a light sever load.

V. Conclusion

Chronic diseases are the long-term diseases and are affected significantly by complications; therefore, a considerable amount of diagnosing information is required. Moreover, the processes of real-time monitoring, multidimensional quantitative analysis, and the classification of a patient's diagnostic information are necessary. In this paper, we first used the basic examining and sensing results to differentiate patients, after which we determined the possibility of disease after extracting the dangerous elements pertaining to patients. Finally, we calculated the health risk according to the dangerous elements of the patients, i.e., the different statuses of the patients. The following shows the process of multidimensional analysis: 1) redefinition of a cost-effective PSCM through a new quantitative classification and multidimensional analysis method for chronic disease and 2) improved usability of the system, which physicians and chronic patients can use with good cost effectiveness.

In the process of the multidimensional analysis, two scenarios in terms of diabetic complications and arrhythmia heart disease were tested so as to test the validity of the system. Using the results, we were able to solve two problems in the systems: medical service expenditures and the processing time to identify metabolic disease. According to the proposed medical information services, we can monitor patients' statuses in a real-time manner even if we are moving or engaged in another task. By doing this, we can provide more opportunities for early diagnoses for patients and, then, give a more flexible treatment compared to reacting to a patient's urgent situation. In addition, the main function of the integrated visualization system can display the patients' information according to its priority levels so as to reduce the burden of information reorganization as well as the cost of diagnose. From another point of view, the integrated visualization system can provide the patient with chances to see their own health status and determine their own self-health management strategy.

Acknowledgment

The authors would like to thank the peer reviewers for their valuable comments. The authors would also like to thank Guest Editors, Prof. Zhang (Editor-in-Chief of TITB), Dr. Poon (Managing Editor of TITB), and the Senior Editor-in-Charge of the IEEE Transactions on Information Technology in Biomedicine. The first author would like to thank Y. Choi at SK Biopharmaceuticals for her passionate discussions on the initial draft of this paper.

References

[1] S. L. Grimes, "The challenge of integrating the healthcare enterprise," *IEEE Eng. Med. Biol. Mag.*, vol. 24, no. 2, pp. 122–124, Mar./Apr. 2005.

[2] K. Kakousis, N. Paspallis, and G. A. Papadopoulos, "A survey of software adaptation in mobile and ubiquitous computing," *Enterprise Inf. Syst.*, vol. 4, no. 4, pp. 355–389, Oct. 2010.

[3] I. Korhonen, J. Parkka, and M. Van Gils, "Health monitoring in the home of the future," *IEEE Eng. Med. Biol. Mag.*, vol. 22, no. 3, pp. 66–73, May/Jun. 2003.

[4] J. Boyle, N. Bidargaddi, A. Sarela, and M. Karunanithi, "Automatic detection of respiration rate from ambulatory single-lead ECG," *IEEE Trans. Inf. Technol. Biomed.*, vol. 13, no. 6, pp. 890–896, Nov. 2009.

[5] C.-H. Youn, E. B. Shim, S. Lim, Y. M. Cho, H. K. Hong, Y. S. Choi, H.-D. Park, and H. K. Lee, "A cooperative metabolic syndrome estimation with high precision sensing unit," *IEEE Trans. Biomed. Eng.*, vol. 58, no. 3, pp. 809–813, Mar. 2011.

[6] C. Schoen, R. Osborn, S. K. H. How, M. M. Doty, and J. Peugh, "In chronic condition: Experiences of patients with complex health care needs, in eight countries, 2008," *Health Affairs*, vol. 28, no. 1, pp. w1–w16, Jan./Feb. 2009.

[7] L. Li and W. Benton, "Hospital capacity management decisions: Emphasis on cost control and quality enhancement," *Eur. J. Oper. Res.*, vol. 146, no. 3, pp. 596–614, May 2003.

[8] L. Li and D. Collier, "The role of technology and quality on hospital financial performance: An exploratory analysis," *Int. J. Service Ind. Manage.*, vol. 11, no. 3, pp. 202–224, 2000.

[9] U. S. Institute of Medicine, *Crossing the Quality Chasm: A New Health System for the 21st Century.* Washington, DC: National Academy Press, 2000.

[10] F. Kart, G. Miao, L. E. Moser, and P. M. Melliar-Smith, "A distributed e-healthcare system based on the service-oriented architecture," in *Proc. IEEE Int. Conf. Services Comput.*, 2007, pp. 652–659.

[11] J. E. Epping-Jordan, R. Bengoa, and D. Yach, "Chronic conditions—the new health challenge," *South African Med. J.*, vol. 93, no. 8, pp. 585–590, Aug. 2003.

[12] T. Bodenheimer, K. Lorig, H. Holman, and K. Grumbach, "Patient self-management of chronic disease in primary care," *J. Amer. Med. Assoc.*, vol. 288, pp. 2469–2475, 2002.

[13] R. March, "Delivering on the promise of personalized healthcare," *Personalized Med.*, vol. 7, no. 3, pp. 327–337, May 2010.

[14] V. G. Koukias, I. Chouvarda, A. Triantafyllidis, A. Malousi, G. D. Giaglis, and N. Maglaveras, "A personalized framework for medication treatment management in chronic care," *IEEE Trans. Inf. Technol. Biomed.*, vol. 14, no. 2, pp. 464–472, Mar. 2010.

[15] I. K. Kim, S. H. Lee, and H. J. Seo, "Agent based interaction model for electronic health record system," in *Multi-Agent Systems for Society*. vol. 4078, New York: Springer-Verlag, 2009, pp. 337–350.

[16] L. Li and W. Benton, "Hospital technology and nurse staffing management decisions," *J. Oper. Manage.*, vol. 24, no. 5, pp. 676–691, 2006.

[17] L. Li and T. Butler, "The influence of management decisions on hospital efficiency: A two-period study," *Int. J. Oper. Quantitative Manage.*, vol. 11, no. 1, pp. 15–34, 2005.

[18] L. Li, W. C. Benton, and K. Leong, "The impact of strategic operations management decisions on community hospital performance," *J. Oper. Manage.*, vol. 20, no. 4, pp. 389–408, Aug. 2002.

[19] R. Fensli, J. G. Dale, P. O'Reilly, J. O'Donoghue, D. Sammon, and T. Gundersen, "Towards improved healthcare performance: Examining technological possibilities and patient satisfaction with wireless body area networks," *J. Med. Syst.*, vol. 34, no. 4, pp. 767–775, 2010.

[20] G. Huang and L. Li, "A mathematical model of infectious diseases," *Ann. Oper. Res.*, vol. 168, no. 1, pp. 41–80, 2009.

[21] H. Schutz, S. Speckesser, and G. Schmid. (1998). Benchmarking labour market performance and labour market policies: Theoretical foundations and applications, Discussion paper FS I 98-205 [Online]. Available: http://hdl.handle.net/10419/43918

[22] G. Schmid, H. Schutz, and S. Speckesser, "Broadening the scope of benchmarking: radar charts and employment systems," *Labour*, vol. 13, no. 4, pp. 879–899, Dec. 1999.

[23] "National diabetes fact sheet: General information and national estimates on diabetes in the United States," Division of Diabetes Translation, Centers for Disease Control and Prevention, U.S. Department of Health and Human Services, Atlanta, GA, Nov. 2005.

[24] A. Stancoven and D. K. McGuire, "Preventing macro vascular complications in type 2 diabetes mellitus: Glucose control and beyond," *Amer. J. Cardiol.*, vol. 99, no. 11, pp. S5–S11, 2007.

[25] Y. S. Kim, "Lifetime health maintenance program for Koreans," *J. Korean Med. Assoc.*, vol. 46, no. 11, pp. 1035–1046, Nov. 2003.

[26] C. H. Salvador, M. P. Carrasco, M. A. G. de Mingo, A. M. Carrero, J. M. Montes, L. S. Martin, M. A. Cavero, I. F. Lozano, and J. L. Monteagudo, "Airmed-cardio: A GSM and internet services-based system for out-of-hospital follow-up of cardiac patients," *IEEE Trans. Inf. Technol. Biomed.*, vol. 9, no. 1, pp. 73–85, Mar. 2005.

[27] R. Mietzner, F. Leymann, and T. Unger, "Horizontal and vertical combination of multi-tenancy patterns in service-oriented applications," *Enterprise Inf. Syst.*, vol. 5, no. 1, pp. 59–77, Jan. 2011.

[28] L. Li, L. Xu, H. A. Jeng, D. Naik, T. Allen, and M. Frontini, "Creation of environmental health information system for public health service: A pilot study," *Inf. Syst. Frontiers*, vol. 10, no. 5, pp. 531–542, 2008.

[29] A. Shaikh, M. Memon, N. Memon, and M. Misbahuddin, "The role of service oriented architecture in telemedicine healthcare system," in *Proc. Int. Conf. Complex, Intell. Softw. Intensive Syst.*, 2009, pp. 208–214.

[30] E. Xu, M. Wermus, and D. Bauman, "Development of an integrated medical supply information system," *Enterprise Inf. Syst.*, vol. 5, no. 3, pp. 385–399, 2011.

[31] L. Xu, "Information architecture for supply chain quality management," *Int. J. Prod. Res.*, vol. 49, no. 1, pp. 183–198, 2011.

[32] Y. Yin, Y. Fan, and L. Xu, "EMG & EPP-integrated human-machine interface between the paralyzed and rehabilitation exoskeleton," *IEEE Trans. Inf. Technol. Biomed.*, doi: 10.1109/TITB.2011.2178034, 2012.

[33] H. Xuan, L. Xu, and L. Li, "A CA-based epidemic model for HIV/AIDS transmission with heterogeneity," *Ann. Oper. Res.*, vol. 168, no. 1, pp. 81–99, 2009.

[34] J. Kim, C. H. Youn, J. M. Woo, S. Jung, and D. Kim, "Association of heart rates with stress response inventory scores in different age groups,"

in *Proc. 29th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.*, 2007, pp. 5751–5753.

[35] J. Kim, C.-H. Youn, D. Kim, J. M. Woo, and S. Jung, "Cost-minimized e-health service for identification of mental stress related heart rate changes," in *Proc. 4th IEEE/Eng. Med. Biol. Soc. Int. Summer School Symp. Med. Devices Biosensors Conf*, 2007, pp. 102–106.

[36] C. H. Youn, J. Kim, H. Song, D. Kim, and E. B. Shim, "Information driven e-health service for identification of heart rate changes from mental stress," *J. IEICE Trans. Inf. Syst.*, vol. E90-D, no. 12, pp. 2104–2107, Dec. 2007.

[37] E. B. Shim, S.-B. Hong, K. M. Lim, C. H. Leem, C.-H. Youn, H.-N. Pak, Y. E. Earm, and D. Noble, "New index for categorising cardiac reentrant wave: In silico evaluation," *IET Syst. Biol.*, vol. 5, no. 5, pp. 317–323, 2011.

[38] H. K. Lee, Y. M. Cho, S. H. Kwak, S. Lim, K. S. Park, and E. B. Shim, "Mitochondrial dysfunction and metabolic syndrome-looking for environmental factors," *Biochimica et Biophysica Acta—Gen. Subjects*, vol. 1800, no. 3, pp. 282–289, Mar. 2010.

[39] H. K. Lee, J. H. Song, C. S. Shin, D. J. Park, K. S. Park, K. U. Lee, and C. S. Koh, "Decreased mitochondrial DNA content in peripheral blood precedes the development of non-insulin-dependent diabetes mellitus," *Diabetes Res. Clin. Practice*, vol. 42, no. 3, pp. 161–167, Dec. 1998.

[40] R. Tretola, *Beginning Adobe AIR*, Indianapolis: Wiley Publishing, 2008.

[41] G. Frederick and R. Lal, *Beginning Smartphone Web Development*, New York: Academic Press, 2009.

[42] C. S. Barnes, D. C. Ziemer, C. D. Miller, J. P. Doyle, C. Watkins, Jr., C. B. Cook, D. L. Gallina, I. el.-Kebbi, W. T. Branch, Jr., and L. S. Phillips, "Little time for diabetes management in the primary care setting," *Diabetes Educator*, vol. 30, no. 1, pp. 126–135, 2004.

[43] E. Saunders, "Time study of patient movement through the emergency department: Sources of delay in relation to patient acuity," *Ann. Emergency Med.*, vol. 16, no. 11, pp. 1244–1248, Nov. 1987.

[44] D. M. Smith, D. K. Martin, C. D. Langefeld, M. E. Miller, and J. A. Freedman, "Primary care physician productivity," *J. Gen. Internal Med.*, vol. 10, no. 9, pp. 495–503, 1995.

[45] H. Kim, C.-H. Youn, D. H. Kim, H. Song, and E. B. Shim, "Adaptive workflow-policy based management scheme for advanced heart disease identification," in *Proc. 10th Int. Symp. Pervasive Syst., Algorithms, Netw.*, 2009, pp. 545–549.

Sangjin Jeong received the B.S. and M.S. degrees in computer science, and information and communications engineering from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea, in 1991 and 2001, respectively, where he is currently working toward the Ph.D. degree in the Department of Information and Communications Engineering.

He is also a Senior Researcher with the Standards Research Center, Electronics and Telecommunications Research Institute, Daejeon. His research interests include network virtualization for future Internet, energy efficient networking, and cloud-based healthcare system.

Mr. Jeong is actively participating in several major standardization bodies, such as Internet Engineering Task Force (IETF), International Telecommunications Union (ITU-T), and International Organization for Standardization, and has authored several IETF Request-For-Comments and ITU-T Recommendation.

Chan-Hyun Youn (S'84–M'87) received the B.Sc. and M.Sc. degrees in electronics engineering from Kyungpook National University, Daegu, Korea, in 1981 and 1985, respectively, and the Ph.D. degree in electrical and communications engineering from Tohoku University, Sendai, Japan, in 1994.

From 1981 to 1883, he was with Korean Army as a Communications Officer, First Lieutenant. From 1986 to 1997, he was the leader of high-speed networking team at Korea Telecom (KT) Telecommunications Network Research Laboratories, where he was involved in the research and development of centralized switching maintenance system, maintenance and operation system for various electronic switching systems, high-speed networking, and HAN/B-ISDN network testbed. He was a Principal Investigator of high-speed networking projects including asynchronous transfer mode technical trial between KT and Kokusai Denshin Denwa Company, Ltd., Japan, Asia-Pacific Information Infrastructure testbed, Korea Research and Education Network, and Asia-Pacific Advanced Network. Since 2009, he has been a Professor in the Department of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea. He was also a Dean of Office of Planning Affairs and the Director of Research and Industrial Cooperation Group, Information and Communications University, in 2006 and 2007. In 2003, he was a Visiting Professor at the Massachusetts Institute of Technology (MIT), Cambridge, where since 2002 he has been involved in the development of Physio-Grid system with Prof. R.G. Mark's Group in Laboratory for Computational Physiology. He is also a Director of Grid Middleware Research Center, KAIST, where he is developing core technologies that are in the areas of mobile cloud, cloud collaboration system, Internet computing workflow management, distributed network architecture, communication middleware, advanced e-Healthcare system, e-Health application services, and others.

Dr.Youn is serving as the Editor-in-Chief at the Korea Information Processing Society, the Editor of the *Journal of Healthcare Engineering*, U.K., and was the head of Korea branch (computer section) of the Institute of Electronics, Information and Communication Engineers (IEICE), Japan, during 2009–2010. He is a member of the Korea Information and Communications Society and the IEICE.

Eun Bo Shim received the M.S. and Ph.D. degrees in mechanical engineering from the Korean Advanced Institute of Science and Technology, Daejeon, Korea, and the Ph.D. degree in physiology from the Graduate School of Medicine, Kyoto University, Kyoto, Japan.

He is currently a Full Professor of mechanical and biomedical engineering at Kangwon National University, Chuncheon, Korea, and the Director of the National Research Laboratory, Seoul, Korea, on biosystems engineering funded by the Korea Government. His current research interests include the broad areas of biosystems modeling such as the development of virtual heart and theoretical analysis for heart diseases.

Moonjung Kim received the M.S. degree from the Korea Advanced Institute of Science and Technology, Daejeon, Korea, in 2011.

She is currently with Mobile Communications Company, LG Electronics Inc., Seoul, Korea, where she was a Research Engineer. Her research interests include human–computer interaction and cloud computing networks.

Young Min Cho received the M.D. and Ph.D. degrees from the Seoul National University College of Medicine, Seoul, Korea, in 1996 and 2004, respectively.

He was trained in the Department of Internal Medicine, Seoul National University Hospital, Seoul. He is currently an Assistant Professor at the Seoul National University College of Medicine. His research interests include pathophysiology and treatment models of diabetes or obesity.

Limei Peng received the M.S. and Ph.D. degrees from the Chonbuk National University, Chonbuk, Korea, in 2006 and 2010, respectively.

She was a Postdoctoral Fellow at Grid Middleware Research Center, Korea Advanced Institute of Science and Technology, Korea. She is currently an Associate Professor in the School of Electronic and Information Engineering, Soochow University, Suzhou, China. Her research interests include optical communication networks and protocols, datacenter networks, optical fiber sensor networks, and cloud computing networks.