

Requirement Analysis and Architecture Design for Ubiquitous Healthcare Service Systems

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Abstract

Various kind of ubiquitous healthcare services have been developed and tried in patient care and health care fields. Due to technical restrictions and not enough application practices, the service systems have been developed somewhat in ad hoc way. This paper describes the requirements for ubiquitous healthcare service systems most of which need to have and presents a ubiquitous healthcare service system architecture with which various ubiquitous healthcare services can be developed. It also introduces an application system for ubiquitous benign prostatic hyperplasia (BPH) patient care which has been developed based on the architecture.

Key Words : ubiquitous healthcare, system architecture, ubiquitous computing, healthcare

1. Introduction

With the advances of communication infrastructures, sensor technologies, and mobile handheld information terminals, the era of ubiquitous computing services is expected to be next door. The increase of an aged population incurs considerable social expenses on their medical and healthcare. Under the circumstances, ubiquitous medical and healthcare services have been attracting attentions.

Various ubiquitous healthcare services have been conceptualized and some pilot applications have been implemented.[2-6] As some representative application domains, there are the ubiquitous diabetic care service, chronic and high-risk patient monitoring, monitoring of patients in home-care settings, and so on. Their enabling technologies include *sensor technologies* such as biosensors, *context-aware sensors* such as location sensors, RFID, visual sensors, *hand-held computing terminals* such as PDAs, mobile phones, *wireless communication technologies* such as WSN (wireless sensor network), BAN(body area network), wireless LAN, CDMA, GPRS and UMTS, and *information processing technologies* such as database managements, knowledge processing and decision support, workflow management, data exchange, security and privacy protection. With the advent of new technologies and new service conceptualizations, various services have been tried in somewhat ad hoc ways.

In this work we have been concerned with the information

processing aspect of ubiquitous healthcare service systems. Most ubiquitous healthcare services are expected to have some common components and similar processing workflows. Despite them, the services have been so far developed from the scratch or some services have been developed without sufficient architectural considerations. In order to help ubiquitous healthcare service development, this paper introduces a conceptual service system architecture which can be used as a guide line in the implementation of ubiquitous healthcare services, and it also presents an ubiquitous healthcare service system for benign prostatic hyperplasia(BPH) patient care which has been developed based on the architecture.

This paper is organized as follows: Section 2 briefly reviews some related works on the ubiquitous healthcare service systems. Section 3 describes the requirement analysis results for ubiquitous healthcare service systems and Section 4 presents the proposed ubiquitous healthcare service system architecture and the components commonly required for the implementation of the servers and clients in the ubiquitous healthcare services. Section 5 briefly introduces a ubiquitous healthcare service system for BPH patient care. Section 6 draws the conclusions.

2. Related Works

Both academia and industries have paid special attentions to ubiquitous healthcare services and as a result several pilot ubiquitous healthcare services have been demonstrated.[2-6] Without doubt, many ubiquitous healthcare services will be available quite soon and give lots of benefits to everyday life. According to the beneficiaries, we could categorize the ubiquitous healthcare services into 3 classes as follows: *patient services*, *personal healthcare services* and *physician assistant*

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services. The patient services are to give healthcare services to patients, such as remote monitoring of chronically ill patients, remote assistance of medical treatment and follow-up for patients, and so on. The personal healthcare services are to help people get some assistance for their healthcare, such remote monitoring physical states with automatic acquisition of various vital signs, remote assistance in case of accidents and emergencies, follow-up of personal physical exercise and nutrition states. The physician assistant services are to help physicians and personal healthcare consultants care about their patients and clients, such as remote access to patients' medical or clients' health/exercise/ nutrition records, remote recommendations and follow-up of the states of their patients or clients.

The followings are some well-known services which have been developed for ubiquitous Healthcare. MobiHealth[2] is a mobile healthcare project funded by the European Commission. The MobiHealth system allows patients to be fully mobile while undergoing health monitoring. The patients wear a lightweight monitoring system which is customized to their individual health needs. A patient who requires monitoring for short or long periods of time does not have to stay in hospital for monitoring. The system has targeted as the early stage domains the services for home care, trauma, and ambulatory monitoring. The MobiHealth service and application platform enables monitoring, storage and transmission of vital signs data coming from the patient BAN. The MobiHealth application platform focuses on the BAN-oriented sensory processing and data communication.

CodeBlue[3] is a healthcare project supported by grants from the National Science Foundation, National Institutes of Health, U.S. Army, and several companies. CodeBlue is a scalable software infrastructure for wireless medical devices designed to provide routing, naming, discovery, and security for wireless medical sensors, PDAs, PCs, and other devices that may be used to monitor and treat patients. Based on wireless sensor networks(WSN), the project have been working on the technologies for a range of medical applications, including pre-hospital and in-hospital emergency care, disaster response, and stroke patient rehabilitation. With the help of wireless medical devices and wireless sensor networks, they want to develop applications which allow vital signs to be automatically collected and fully integrated into the patient care record and used for real-time triage, correlation with hospital records, and long-term observation.

UbiMon[4] is a project addressing general issues related to using wearable and implantable sensors for distributed mobile monitoring. UbiMon is a network of sensors that would be implanted on someone's body. The sensors would send data to a device such as PDAs, phones. The data could even be delivered to a medical facility for analysis and storage. In the network, wearable communicators perform multi-sensor interfacing and automated techniques are devised to integrate multi-sensory data leading to an intervention strategy. Preliminary clinical evaluation has been done for the management of patients with ischaemic and arrhythmic heart disease. The UbiMon project is to investigate mobile integration issues re-

lated to novel miniaturised low power sensor interface circuitry design and distributed computing environment for multi-sensory data fusion and decision support.

From the literature of ubiquitous computing, healthcare has been considered as one of important service applications as in Smart Medical Home project[5], the Aware Home Project[6]. Due to their early immature stage, ubiquitous healthcare services have been developed from the scratch without following the standardized architecture or reusing available components. This paper proposes a conceptual architecture for ubiquitous healthcare service systems.

3. The Requirements for Ubiquitous Healthcare Service Systems

In order to develop a system architecture for the ubiquitous healthcare services, it is the first thing to analyze the requirements for them. The followings are the characteristics identified in the course of the service analysis.

Ubiquitous Accessibility: The services need to be accessible anytime, anywhere, and with any device. Therefore, the service systems are expected to provide both wired and wireless connections, and to support various available communication terminals for the data acquisition and user interfaces.

Flexible Medical and Health Data Acquisition: In the healthcare services, it is essential to collect the medical and health-related data from the healthcare beneficiaries in automatic, semi-automatic, or sometimes manual manners. Therefore, the communication terminals might have to manipulate several biometric and context-aware sensors by organizing and controlling a WSN or a BAN.

User-Friendly Interface: The service systems need to provide user-friendly interfaces to the healthcare beneficiaries and the healthcare people like physicians, healthcare experts. Special attentions have to be paid to the interfaces for wireless handheld devices.

Automatic Decision Making and Response: To take care of emergency situations and to enable labor-saving service furnishing, the systems are expected to determine the beneficiaries' states in an automatic way based on the compiled knowledge and to inform the beneficiaries and the healthcare people of the monitoring results and the required actions, if any.

Healthcare Data Management: The systems need to store the collected data from beneficiaries and healthcare people and allow the developed services to manipulate the stored data. The database system has to manage data in some standard formats for easy data exchange and synchronization.

Healthcare Knowledge Management: The medical and healthcare knowledge is crucial to embody healthcare services because diagnosis and follow-up treatments should be based on the expertise. The system should be equipped with some mechanisms to accumulate expert domain knowledge and to make use of it.

Workflow Management : Failure-proof mission completion is essential in some services such as emergency handling, seriously ill patient monitoring, solitary elderly person care, and

the like. Therefore, the systems need to be equipped with a workflow management mechanism for critical mission follow-up and activation, log management.

Data Security and Privacy Control: Healthcare services collect and make use of personal data. Personal data are usually privacy-sensitive and have been attracting lots of interests of malicious people. The systems need to provide strong enough data security and privacy protection mechanisms.

Interoperability with External Systems: The healthcare service systems would not work stand only as the ubiquitous healthcare service environments get more mature. Therefore they need to have the capability to interoperate with external systems like hospital systems, insurance company systems, emergency center systems, pharmaceutical company systems, e-government systems, and so on.

Flexible Support for Patient Services, Physician Assistant Services, and Personal Healthcare Services: The healthcare service system architecture should be adequate for all kinds of healthcare services, i.e., patient services, physician assistant services, and personal healthcare services.

4. The Proposed Ubiquitous Healthcare Service System Architecture

Based on the identified requirements on the ubiquitous healthcare service systems, we have designed a conceptual system architecture. The architecture tells what components have to be considered in the implementation of a ubiquitous healthcare service system in terms of data and information processing aspects. As shown in Figure 1, the proposed architecture has been organized with the consideration of *u-healthcare center* which is the central information processing server

for ubiquitous servers, *user front-end* which takes care of collecting healthcare-related data and providing services for the users such as patients, physicians, personal healthcare people, and healthcare experts, *external systems* which might interact with the u-healthcare center, and *communication networks* covering wired and wireless communication channels.

The user front-end is implemented in the ubiquitous healthcare service client platform which could be a mobile handheld device, a wired communication terminal, and a sensor node with sufficient resources such as computing power, battery and communication capability. The client platform is expected to have communication interface module, sensor interface module and user interfaces modules. The communication interface module plays the role to provide the client applications with communication channels to the u-healthcare center over the wired or wireless networks. The sensor interface module takes charge of handling various context-aware and biometric sensors, if they are organized to be used in the service. If a WSN or a BAN is configured around the healthcare beneficiaries, the sensor interface module is responsible for all networking tasks like configuration, routing, discovery, scheduling, and data collection. The WSN and BAN have been actively yet worked, and thus the architecture tells that such well-established sensor interface module should be employed in the healthcare service development. Depending on the types of services(i.e., patient services, physician assistant services, and personal healthcare services), dedicated client applications should be developed. For the friendly and easy-to-use applications, the user front-end needs to contain user-friendly interface components.

The u-healthcare center contains the components for communication interface, workflow monitoring, EMR(electronic medical record) database management, knowledge base management and decision making, and the components for patient

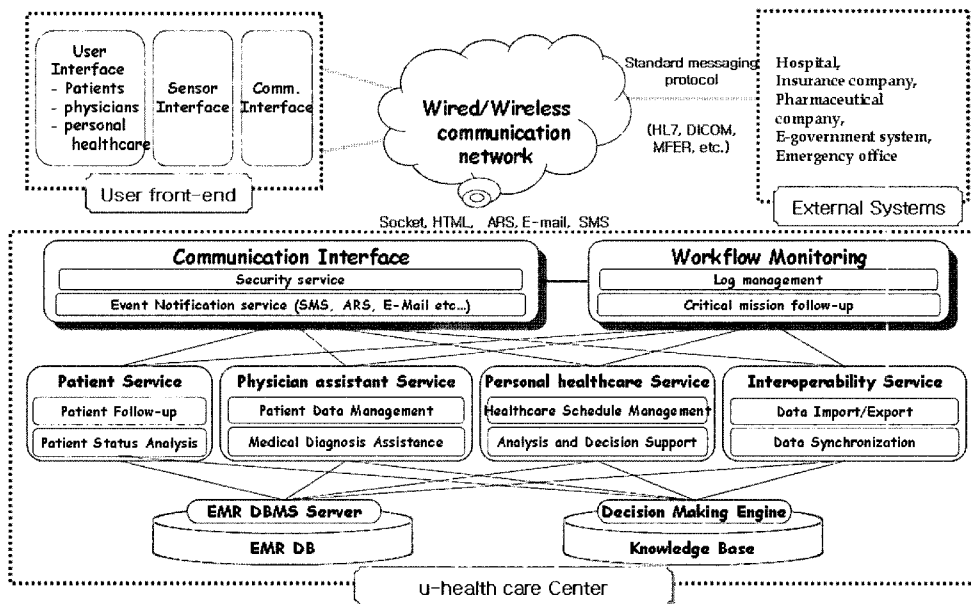


Figure 1. The proposed ubiquitous healthcare service architecture

services, physician assistant services, personal healthcare services and interoperability services. The communication interface takes charge of establishing communication channels with client applications and external systems over wired and/or wireless networks, enforces the security mechanisms and policies for data security and privacy protection, and provides event notification services via SMS, ARS, e-mail, paging, and the like. The EMR database component manages the medical and healthcare data collected from the user front-end and provides the interfaces for the services built on the server side. The knowledge base component compiles the expert knowledge for patient care and personal healthcare and provides the decision making module which automatically diagnoses the states of the healthcare beneficiaries and determines the actions to be taken based on the deduced states and the compiled knowledge. The patient services are to care about patients in a remote manner and usually to contain the patient follow-up and patient status analysis modules along with the underlying architectural services. The physician assistant services help the physicians and healthcare personnels take care of their patients and clients in effective ways. Therefore, they need patient/client data management and medical/health diagnosis assistance modules. The personal healthcare services are used by the individuals to take care of their health and thus they contains the modules for healthcare schedule management and automatic health/physical exercise/nutrition state analysis and decision support. For the service effectiveness and efficiency, the ubiquitous healthcare service systems need to exchange their own data with external systems with the shared standard protocols like HL7, DICOM, MFER. The interoperability services are implemented with the components for data import and export, data synchronization.

In the architecture, a patient or a client sends her medical or health-related data from the user front-end to her u-healthcare center service (i.e., either patient service or personal healthcare service), her state is automatically determined by the service and she is informed of it. On the other hand, when her state needs to be paid attention, her physician or healthcare personnel should be informed automatically. Sometimes, some external system like an emergency center should be informed in the case of emergency without failure. When her healthcare personnel is notified to pay attention to the patient or client, the personnel should be able to check her record at the moment in a ubiquitous way. These workflows should be run without failure and delay, therefore the architecture has to be equipped with the workflow monitoring component for critical mission follow-up and log management. When a ubiquitous healthcare service system is developed, it would be desirable to design the system with consideration of the proposed architecture. Some architectural components could be optional depending on the applications. For example, a stand-alone service system might not have the interoperability functionality.

Figure 2 shows the components which are commonly required to implement a server system for ubiquitous healthcare services. The Process Design component is an environment with which the developers can easily describe the service

processes with the components provided in the development framework, and later on compile them into executable service modules. The Process and Workflow Execution component is to run the developed service processes and keep track of their workflow. The Communication Interface component is to provide basic modules which can be easily employed to develop communication interfaces for the external clients and systems. The Notification component plays the role of sending messages to corresponding participants in various ways. The Decision Support component provides interfaces for the decision support modules such as machine learning, data mining, ontology and knowledge base, diagnosis, etc. The Database Management component is the package with which the developers easily create databases and manage them. The Data Exchange component provides the modules for data exchange with external systems. The Privacy and Security component is a collection of services for privacy protection and security enforcement. The Schedule Management component is a module to set schedules for participants and to inform them of the scheduled tasks on time with the help of the Notification component. The Automatic Diagnosis component is a monitoring module which checks whether the specified events take place or deduce the cause-effect relationships based on the available data. The Machine Learning and Data Mining component is a package that provides various modules for machine learning algorithms and data mining tools. The Ontology and Knowledge Base component is a subsystem that maintains the ontology for the services and the knowledge base for decision making and service provision. The Import and Export component has the role of sending out the specific data from the database and putting into the database the data originated from the external system. The Pattern Recognition component is a collection of modules designed for pattern recognition. Once the above-mentioned components are facilitated for the developed healthcare service system architecture, the development cost and effort could be drastically reduced and the interoperability among the developed systems could be a lot improved.

Process Design	Process & Workflow Execution		Communication interface	notification
Decision Support	Database Management	Data Exchange	Privacy & Security	Schedule management
Automatic Diagnosis	Machine Learning Data Mining	Ontology & Knowledge base	Import/Export	Pattern Recognition

Figure 2. Components used to implement a server system of ubiquitous healthcare services

Sensor data acquisition	communication	User Interface
	Privacy & Security	

Figure 3. Components used to implement the client application for a ubiquitous healthcare service

Figure 3 shows the basic components which are expected to be used in the development of ubiquitous healthcare client applications. As the hardware platforms for ubiquitous healthcare clients, we have various options and are expecting new advanced ones near future. Those platforms need to have the following components in some ways: The Sensor Data Acquisition components is tightly coupled with the hardware platform, yet the framework needs to regulate the standardized interface provision for the hardware platform vendors. The Communication component is to provide various options for communication with the servers. The Privacy and Security component is the modules for providing the privacy protection and security at least at the minimum level. The User Interface module is a collection of modules for easy interface development in the implementation of client applications.

5. An Application of the Proposed Architecture to Benign Prostatic Hyperplasia Patient Care System

5.1 The Benign Prostatic Hyperplasia Patient

As a practical ubiquitous healthcare service system, we have developed a benign prostatic hyperplasia(BPH) patient management service which adopted the proposed architecture in its implementation, through the collaborative works with the urological medical doctors. BPH is a typical urinary chronic disease which lots of aged people could be suffering from as they get older. Usually the disease does not threaten the life, but degrades the quality of life. The patients with this disease need to see doctors on a regular basis, e.g. once or twice a month depending on their disease severity, in order to check up and treat the disease over their aged life. Therefore, this kind of urinary diseases cost lots of time and money. In order to help patients reduce the number of their hospital visits and

to provide better medical care services for the BPH patients, we have developed a prototype system with which the BPH patients are cared. The system has been designed according to the above-presented ubiquitous healthcare service architecture.

In the developed system, the BPH patient care service is practiced as follows: At the first visit of a BPH patient to a hospital, the physician registers him into the system and records all pieces of information about patients including basic lab tests and observation results like prostate size, prostate specific antigen, digital rectal examination, urine analysis, bun, maximum/average flow rate, blood pressure, waist circumference, weight, and so on. According to the diagnosis results, the physician issues a prescription for the patient and sets for the patient the next hospital visit date which is somewhat farther than in the conventional treatment. At home, the patient observes his symptoms by himself and enters them into the system using a mobile device like a PDA phone or a wired Web application on a regular basis (e.g., once a week). Each time the system receives a patient's input about his symptoms, it decides his disease state using the diagnosis knowledge constructed by the BPH specialists and determines whether it is good for him to visit the hospital on the scheduled date. Depending on the decision, the system sends the patients a message about hospital visit schedule. If the diagnosis tells that his disease state gets worse, the system informs him of an urgent visit. With the help of the system, the BPH patients can lessen the number of their hospital visits yet they receive the quality care for themselves.

5.2 The Developed Benign Prostatic Hyperplasia Patient Care System

Figure 2 shows the schematic diagram of the developed system which provides the healthcare services for the BPH patients. The system consists of several distributed servers and modules as follows: Patient Data Communication Software, Patient Web Interface Physician side Patient Information

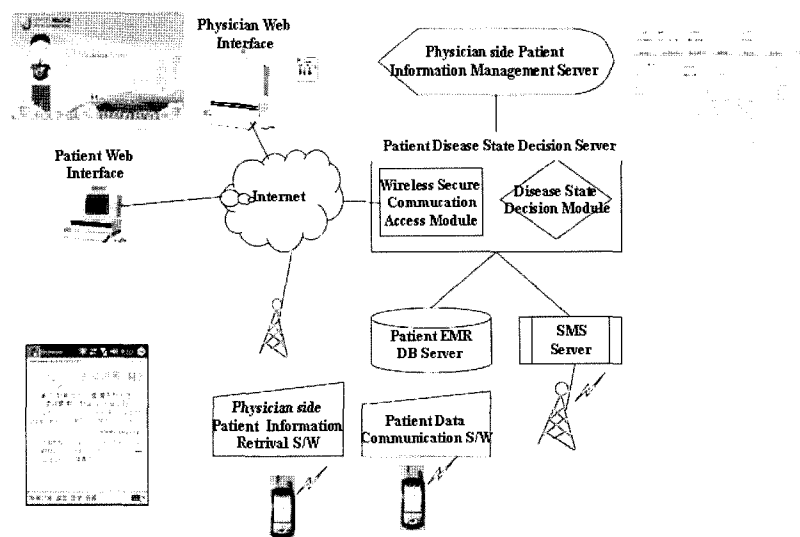


Figure 4. The BPH Patient Care Service System

Retrieval Software, Patient EMR DB Server, SMS Server, Patient Disease State Decision Server, and Physician side Patient Information Management Server.

In order to cause their disease state to be followed up, the BPH patients need to report their symptoms to the hospital or their physician on a regular basis while they stay home. As one of data terminals for patients, PDA phones have been employed which have the computing capability as well as wireless communication capability. We have developed a PDA program which helps the BPH patients to answer the questionnaire[10,11] about their symptoms and sends the answers to the Patient Disease State Decision Server. Despite the PDA phones are an excellent platform to run such software and to make data communication over the wireless Internet, they are still unfriendly especially to the aged people. Hence, we have paid special attention to the user interface design of the PDA program.

The PDA phone-based Patient Data Communication devices are excellent in the perspective of mobility and portability, yet they have some restrictions such as device costs, small screen size, wireless Internet access cost, and so on. Hence, the developed BPH patient care system additionally provides the patients with a web-based interface which has the same functionality as the PDA phone-based program. The Patient Web Interface accesses the hospital servers through the web browsers like MS Internet Explorer over the wired Internet and also provides the audio guidance along with some additional information about BPH management.

The Physician-side Patient Information Management Server takes charge of registering new patients, adding/deleting/updating the records of patients, and retrieving relevant records according to the physicians' requests. When a new patient decides to employ the BPH patient care service, his physician creates a new account for the patient. All pieces of information about the BPH including the basic personal information and lab test results, diagnosis results, prescription, and next hospital visit date come to be stored in the EMR DB server through the Physician side Patient Information Manager Server. Each time the patients see a physician, the physician adds a new record about his/her diagnosis, and some factors such as prostate size, maximum/average flow rate, IPSS score, quality of life score, and so on. When a physician sees a patient, the physician may refer to the patient's past clinical history data with the help of the Patient Information Management Server. In order to make it convenient for the physicians to use the server, the Web-based interface has been implemented and thus they can use the server through a Web browser from any computer over the Internet.

The BPH Patient EMR database is the repository for all pieces of information about the BPH patients served by the BPH Patient Care Service System. For each patient, it keeps the basic personal information, the clinical history data about the lab test results, symptoms submitted by the patients through their PDA phones or Patient Web Interface, and the diagnoses and treatments. The server provides the DB access interface for the other servers like Physician side Patient

Information Management System, Patient Disease State Decision Server, and SMS Server.

The major goal of the developed service is to reduce the number of hospital visits while maintaining the disease control quality level. If a patient seems to remain in same disease state as that of the previous hospital visit or to be improving, the BPH Patient Care system is expected to inform him that he could pay a visit to the hospital on the scheduled date. If a patient is suspected to get the disease state worse, the system recommends him to see doctor immediately or earlier than the scheduled date. In order to make such decision, the service system makes use of medical diagnosis knowledge provided by the BPH medical specialists. When the service system has been developed, the BPH specialists have participated in building the diagnosis knowledge.

After a patient sends his symptoms to the Patient Disease State Decision server, the server makes decision about the hospital visit date with reference to the diagnosis knowledge base. In the course of the decision process, it accesses the patient EMR database and thus takes some time until to inform the patient of the decision. Therefore, instead of notifying its decision during the current Internet access session, the service system sends its decision results to the patient by a SMS(Short Message Send) message. The SMS server sends messages to the patients about the recommended hospital visit date based on the symptom data provided by the patients, and it also plays a role of providing alarm services like notifying the schedule to observe and send their symptoms to the service system, and so on.

With the help of this service system, the physicians could provide better medical care services for the BPH patients and therefore they would be willing to provide advice for their patients when the patients seek for some advice about their disease. To understand a patient's state at the time of advice request, the physicians need to look up the patient's medical records. If the Internet is available around them, they could access the Physician side Patient Information Management server with the Web browsers and get the necessary information. Sometimes, they could not access the Internet even if they want to look at the patient's records. To handle this kind of situations, the Physician side Patient Information Retrieval Software has been developed which runs on a PDA phone and allows the physicians to retrieve patients' records on their PDA phone. With this PDA phone accessibility, the patients could provide necessary advice for their patients at any time, at any place.

6. Conclusions

With the advances of ubiquitous computing infrastructure, ubiquitous healthcare services are expected to be prevalent over next decades. This paper introduced a ubiquitous healthcare service system architecture in which we have identified the required components and their roles. It categories the services into patient services, physician assistant services and personal healthcare services. It tells which service modules are

required for service infrastructure establishment, and which task-specific service modules are useful for each category of services. Based on the proposed architecture, a ubiquitous healthcare service system for BPH patient care has been developed. In the development, the architecture has been partially adopted because the system provides only a combined service of patient care and physician assistance. The system has been developed to apply the service to the BPH patient care from the Urology Department, Chungbuk National University, Korea.

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