Sensor-based Pervasive Healthcare System: Design and implementation

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Abstract. With rapid progress in wireless sensor networks (WSN) and pervasive computing technology, development of WSN-based pervasive healthcare systems, which provide patients and healthcare professionals with a convenient and efficient e-health environment, have become one of important and popular research topics in Health Information Systems (HIS). This paper proposes a Sensor-based Pervasive Healthcare (SPH) System, which comprises the Home Healthcare End (HHE) system, E-healthcare Service Provider (ESP) and E-healthcare Control Center (ECC). At the ECC, healthcare professionals remotely monitor the physiological status of patients using the WSN-based HHE system. The ESPs provide patients and healthcare professionals of the ECC with healthcare information services. The ESP is developed based on proposed Healthcare Service Middleware (HSM), which integrates the heterogeneous computing and communication devices, and provides the flexible healthcare platform to enrich the healthcare services. Additionally, a Seamless Healthcare Information Delivery (SHID) scheme is proposed to allow healthcare professionals to access patients’ with their relevant healthcare data anywhere in real-time without manual manipulations. The ultimate objective of the proposed SPH system is to effectively reduce healthcare labor and to further provide a streamlined, convenient, and low cost healthcare platform for patients and healthcare professionals.

Keywords: E-healthcare system, wireless sensor networks, pervasive computing, seamless handoff, middleware

1. Introduction

With a significant increase in the number of senior citizens in modern society, the demand for senior healthcare also increases. According to the statistics released by the Department of Health of Taiwan [6], most senior citizens suffer from aging and chronic diseases and have been visiting their doctors routinely for regular follow-up. The intention of such a follow-up re-visit usually just wants to have their a few questions answered. But such a simple trip to hospital generally requires their tremendous efforts to make it happen. For example, family members of senior citizens are concerned with their safety and have to make arrangement of their work to accompany them to hospitals. Additionally, the social cost is also far greater than the cost by healthcare treatment. In many remote regions, which lack healthcare resources and doctors, the quality of healthcare service has resulted in high social costs. In order to solve these dilemmas, real-time e-healthcare systems constructed by combining state-of-the-art information technology have been emerged as one of possible solutions that can decrease the social cost of healthcare services, and enhance the quality of healthcare care [3,5,7,8,12,18,19]. Among them are the wireless sensor network (WSN) and pervasive multimedia technologies have received most considerable interest [10,14,22,24,28].

By virtue of WSN-based pervasive medical services [3,15,20,23,25,32], (1) the physiological status of patients can be automatically collected via vital sign sensors, e.g., the electrocardiogram (ECG) sensor, and be transmitted...
to healthcare professionals in real-time for further healthcare services; (2) healthcare professionals can apply mobile appliances, e.g., Personal Computer (PC), Smart Phone, or Personal Digital Assistant (PDA), to receive the patients’ physiological status and connect their devices to healthcare networks to access healthcare information. As an example, the state-of-the-art WSN-based pervasive technology in the emergency rescue system [2, 27] allows the emergency care workers to be able to access treated patients’ blood pressures, heart rates, and images in real time for reference or pre-diagnosis. Additionally, emergency patients can promptly receive adequate healthcare suggestions before they arrive at the hospital so that the quality of healthcare treatment can be improved.

Traditional healthcare needs abundant healthcare service personnel to take care of senior citizens or patients at home or in care centers. As a society becomes aging, developing a streamlined, convenient, and low cost healthcare system using state-of-the-art information technology becomes more evidential and increasingly important. This paper describes a Sensor-based Pervasive Healthcare (SPH) System, which comprises the Home Healthcare End (HHE) system, E-healthcare Control Center (ECC), and E-healthcare Service Provider (ESP). The HHE system is located in a patient’s home or the healthcare center that can use Wireless Sensor Networks (WSNs) to have access to automatically collect patient physiological data [4, 9, 25]. Using WSNs healthcare professionals are able to monitor a patient’s status remotely with no need of paying visits to patients, and thus reduce labor expense as well as social costs. The E-Healthcare Control Center (ECC) system is located in the dedicated hospital or government unit to manage E-healthcare operations. The ECC system is responsible for remotely monitoring the physiological status of patients and coordinating between the HHEs and the ESs when healthcare operations are required. The ESP is responsible for providing the necessary healthcare services, including emergency healthcare services, hospitals, and ambulance services. Since the operating environment of the ESPs is heterogeneous such as PCs, handheld appliances, and different operating systems, the Healthcare Service Middleware (HSM) is built into the ESP system to provide an integrated healthcare services platform over heterogeneous platforms and networks. Healthcare service providers, e.g., Emergency Healthcare Center (EMC), hospitals and ambulances, are based on existing appliances and can then freely join the designed SPH system via the HSM.

With recent advances in development of handheld devices, mobile healthcare services are now be able to provide convenient and flexible solutions for healthcare professionals who can remotely access the healthcare and patients’ information. To address convenient and flexible mobile healthcare services, this paper designs and develops a novel Seamless Healthcare Information Delivery (SHID) which allow the healthcare professionals to conveniently accesses the desired healthcare information remotely, even when they are on move between heterogeneous hosts and platforms.

The remainder of this paper is organized as follows. Section 2 reviews the previous work on WSN-based healthcare systems. Section 3 presents the architecture of our new developed SPH system. Section 4 describes the design and control scheme of the Seamless Healthcare Information Delivery system and its implementation in Section 5. Finally, some conclusions are drawn in Section 6.

2. Previous work

This section briefly reviews relevant literature on e-healthcare and telemedicine systems. Wen and Tan [31] described major opportunities and challenges in telemedicine and e-health. The benefits of telemedicine and e-health systems include improved efficiency, rapid and efficient development of new markets, reduced costs, as well as enhanced quality and value of health service delivery.

Lin and Vassar [16] studied the impact and implementation issues involved in using mobile healthcare computing devices (MHCDs) in the medical community. MHCDs can increase efficiency and effectiveness by sharing real-time patient data, rapidly tracking patient information and significantly reducing paperwork by using electronic prescriptions. This study investigated the major deployment issues involved in using MHCDs, including data security, system interoperability, radio interference, network connectivity, system scalability and patient privacy. Lin et al. previously described the feasible implementation steps including: (i) identifying an organization’s strategic goal and objectives; (ii) understanding the current environment; (iii) identifying the value of a mobile
workforce; (iv) allocating resources and building a team; (v) designing a mobile deployment solution; (vi) successfully deploying the solution; and (vii) determining gains, growth and expansibility. That study also discussed the feasibility and benefits of using MHCDs achieve mobile healthcare applications.

Liang et al. [15] proposed a novel Extended Technology Acceptance Model (TAM) to effectively evaluate PDA use in healthcare organizations. Five theoretical evaluation criteria were considered and investigated: (1) perceived usefulness and ease of use, (2) personal innovation, (3) job relevance, (4) compatibility, and (5) support. Of these five criteria, personal innovation was found to have the most significant effect on PDA use and acceptance. The significance of some factors was mediated by others. For example, perceived job relevance, compatibility, and ease of use were all mediated by perceived usefulness. This study further contributes to theories of IT acceptance by extending the validity of TAM to PDA use. Results of this study provide a valuable reference for healthcare organizations intending to promote PDA use by their healthcare professionals.

Wickramasinghe [32] outlined the benefits of using mobile communications technology in the healthcare sector. An e-healthcare study conducted by INET International, Inc. found that mobile healthcare has the following three advantages: (i) Increased quality of healthcare; for example, radiological test results can be transmitted between hospital and physicians on demand; (ii) reduced cost of rapid healthcare delivery and deployment; for example, a physician can retrieve diagnostic imaging reports from a radiology information system efficiently and economically; (iii) and more efficient medical research and data retrieval; for example, a physician can easily access the latest clinical research to quickly implement new medical procedures and technology.

Healthcare information system development involves various technologies based on different computer languages, platforms, and hardware, and possibly/perhaps even using different data structures and formats. Moreover, modern healthcare information systems often operate independently without sharing data or processes. Thus, current and future healthcare systems need to be integrated to comply with rising clinical, organizational, technical and managerial requirements.

Khoubati et al. [12] presented the merits and limitations of using Electronic Data Interchange (EDI), Enterprise Application Integration (EAI), and web services for integrated managerial processing. Fitch [8] concluded that the most significant problem in integrating medical systems is the inappropriate translation of user requirements into system requirements. This problem is commonly referred to as the “knowledge gap”. This study proposes the Ilities Application Method (IAM) to identify and bridge such knowledge gaps. “Ilities” are the factors affecting telemedicine system design, e.g., reliability, usability, and security factors. IAM classifies different groups of users and priorities to be classified as Ilities as an aid for system design, and then finds and bridges the knowledge gaps.

Tan [29] and Banitsas [1] described the use of Wireless Application Protocol (WAP) and Orthogonal Frequency Division Multiplexing (OFDM) in e-health systems, respectively. Tan [29] focused on the security concerns arising from WAP solutions, and provided insight into some of the benefits associated with WAP-based applications. However, system providers and users seldom use WAP to transmit data via the Internet in modern mobile and wireless communication networks such as Third-generation (3G) and General Packet Radio Service (GPRS) Personal Communications Service (PCS) [11]. Furthermore, the general user interface is currently the Internet Explorer (IE) browser, which provides security using Secure Socket Layer (SSL). Banitsas [1] studied the advantages of using OFDM to reduce interference and multipath phenomena and thus maximize the network bandwidth available for multimedia Quality-of-Service (QoS).

3. System design

The SPH system attempts to develop an automatic and flexible physiology sensing system and to achieve a complete telemedicine, emergency medicine, and healthcare environment in which users can quickly and efficiently receive high quality e-healthcare services.

Figure 1 depicts the SPH system architecture, which is comprised of the Home Healthcare End (HHE) system, E-healthcare Control Center (ECC) and E-healthcare Service Provider (ESP). The development technologies of the system are based on Embedded Wireless Mobile Networks, Wireless Sensor Networks (WSNs), Session Initiation
Protocol (SIP) [26], and Pervasive Computing technology. The system hardware includes Internet Protocol (IP) cameras, vital sign sensors, and various handheld appliances.

According to Fig. 1, the e-healthcare data process is divided into four stages: detection, collection, classification, and presentation. The SPH system provides two e-healthcare messages: regular messages and trigger messages.

1. Regular messages transmit vital patient information such as natural heart rate and blood pressure, videos of the patient and location of the patient. The SPH system periodically and automatically collects and stores the regular information.

2. Trigger messages are issued automatically for abnormal and emergent situations to notify medical personnel of unusual events, e.g., an abnormal increase in heart rate. When a trigger message is received by the SPH system, it is assigned a high priority and preferentially processed. In addition, the SPH system automatically contacts the E-Healthcare Control Center (ECC) to request healthcare assistance.

3.1. Home Healthcare End (HHE)

Figure 2 depicts the HHE sub-system architecture, which consists of (i) Sensor equipment and (ii) Healthcare Engine (HE). The main sensors are the vital sign sensor and the video sensor. The HE attempts to transmit, collect and aggregate the sensed data via the healthcare sensors. HE constantly collects the sensed data and identifies the data message type. If the data message type is “regular”, the sensed data are stored in a database. However, if the data message type is a trigger message, HE automatically notifies the E-healthcare Control Center (ECC) and E-healthcare Service Providers (ESPs) to request healthcare and healthcare support.

3.1.1. Sensor equipment

The HHE system includes vital sign and video sensors. To process the healthcare query commands from the HE, a Transmission Unit and Command Agent (CA) is installed in the sensor unit. When the CA receives the query commands, the sensors begin to monitor the patient’s status, including ECG, heart rate, blood pressure, and images. The transmission unit is responsible for transmitting the sensed healthcare data to the HE system via wireless network.
3.1.2. Healthcare engine

The HE system is responsible for transmitting the query commands to monitor the patient’s health status and receive data from the sensors. The HE system also provides a universal interface for communicating with e-healthcare service providers (ESPs) and for exchanging information between HE and ESP. Additionally, HE has a web-based and user-friendly interface which allows simple configuration of system parameters. The functions of the HE system are as follows:

1. **Air Interface Base Station (AIBS):** AIBS is a wireless network base station which relays sensor messages and sensed data between sensor equipment and the HE system. The transmission protocols for AIBS may be Third-generation (3G) and wireless network.

2. **Command Processor (CP):** The CP is an interface for sensing parameters for users. The CP processes the sensing parameters and transfers them to sensor equipment via AIBS. The sensing parameters include attributes such as heart rate, blood pressure, ECG and sampling rates of sensors.

3. **Data Collection Module (DCM):** The DCM receives the healthcare sensed data from the CA of sensor equipment. The DCM attempts to collect all sensed data from each sensor.

4. **Data Classification Module (DCFM):** The DCFM identifies the type of sensed data received. The sensed data may be regular message or trigger message. If the data type is a trigger message, the HE system triggers an Instant Message Module (IM2) to send an instant message to the E-healthcare Control Center (ECC) and related ESP such as hospitals and ambulances for emergency operations.

5. **Data Aggregation Module (DAM):** Since different sensor equipment differs in terms of the sensing functionality and some errors may occur during the transmission from CA, DAM aggregates and corrects the sensed data flows. DAM eliminates errors to provide highly accurate health data for ECC and ESP.

6. **Instance Message Module (IM2):** IM2 distributes instant messages to ECC and ESPs after receiving a trigger message. For universal communication between e-healthcare systems, IM2 adopts the Session Initiation Protocol (SIP) and Session Description Protocol (SDP) as the signaling protocol.

7. **XML Generator (XMLG):** XMLG is an XML document generator which retrieves the historical sensed data and generates an XML document from the database based on user requirements. A user can browse
XML-based documents via various appliances on a heterogeneous operating system. XML-based documents efficiently reduce the processing overhead of the database and network.

- **Database Driver Interface (DDI):** The DDI mechanism, which facilitates the HE in accessing a database, is a bridge between the HE and a database. Since the HE system exploits JAVA development tools, the interface driver of the DDI mechanism adopts Java Database Connectivity (JDBC) to support JAVA database programming for ease of system integration.

- **Local Database (LS):** DS stores the historical healthcare data of patients and healthcare professionals. Developers can access the stored data using the standard Structured Query Language (SQL) language via DDI.

- **HE Universal Interface (HE-UI):** The HE-UI mechanism provides a universal interface for establishing connections between the HE system, ECC, and each ESP, thus assisting exchange of information between Home Healthcare End (HHE) system, ECC, and ESPs.

- **Web-based Configuration Interface (WCI):** Due to the limited processing capability of sensors, direct configuration of sensing parameters is difficult. To simplify the procedure for configuring sensors, the WCI mechanism provides a friendly web-based interface for simple user configuration of the required sensing parameters, sensing attributes and sensing interval.

### 3.2. E-healthcare Control Center (ECC)

The E-healthcare Control Center (ECC) remotely monitors the physiological status of patients and coordinates between HHEs and ESPs when healthcare operations are required. Figure 3 depicts the ECC system architecture, which is comprised of the location service mechanism, registrar server, session agent, mobility agent, and third-party and HE universal interfaces. Each component has the following functions.

![E-healthcare Control Center (ECC) system architecture](image-url)
(1) Location Service (LS) mechanism: The LS mechanism records the location of each patient. When receiving a trigger message, the LS mechanism traces the current location of the patient and establishes communication between the HHE system (patient) and ESP (hospital) with the assistance of the Session Agent (SA).

(2) Registrar Server (RS): The RS is responsible for the authorization, authentication, and accounting for users. The RS adopts the Session Initiation Protocol (SIP) as the signaling protocol for universal communication with users’ heterogeneous environments.

(3) Session Agent (SA): The SA establishes a communication session which enables the transfer of audio, video, and text data between patients and ESP when a trigger message occurs. In an emergency situation, an Emergency Healthcare Center (EMC) can dispatch an ambulance to the current location of the patient via the established communication session. Furthermore, SA assists in establishing the communication session between the ambulance and any designated hospital where a patient may be directed for further healthcare services.

(4) Mobility Agent (MA): The MA assists healthcare professionals in using the same session service across heterogeneous networks and appliances. To achieve seamless handoff operation, a Seamless Healthcare Information Delivery (SHID) scheme is proposed. The SHID control scheme allows healthcare professionals to monitor heart rate, blood pressure and ECG of the patients at any location and at any time using any hosts without service interruption. Section 4 describes the details of the SHID scheme.

(5) Network Adapter (NA): The NA is responsible for data transmission based on the available networks, e.g., GPRS and the Internet.

(6) Third-party Universal Interface (3rd-UI) and HE Universal Interface (HE-UI): These two interfaces are responsible for message exchange and format conversion between the HHE and the ECC.

3.3. E-healthcare Service Provider (ESP)

The ESP is responsible for providing necessary healthcare services, including emergency healthcare centers (EMCs), hospitals and ambulances. Since the operating environment of ESPs is heterogeneous and may include PCs, handheld appliances, and different operating systems, the Healthcare Service Middleware (HSM) is embedded into the ESP system to achieve a flexible platform. Figure 4 depicts the HSM system architecture. HSM has the following functions.

(1) Instant Message Module (IM2): The IM2 is responsible for receiving and sending instant messages. When an abnormal or emergency event occurs, the HHE system transmits an instant message to request assistance from the ESP.

(2) Push Agent (PA): The PA is responsible for automatically extracting information contained in the XML document and, then promulgating the extracted information to the HHE and the ECC periodically. Examples of extracted information are healthcare services provider information, service types, and accounting services.

(3) XML Profile (XMLP) and XML Generator (XMLG): The XMLP records information regarding ESPs, including service capability, accounting criterion and service types. The XMLG aggregates the information from XMLP and generates the XML-based documents for ESP use.

4. Seamless Healthcare Information Delivery (SHID)

In conventional healthcare information systems, healthcare professionals could only use specific PCs or workstations to view patient data at specific locations. However, busy healthcare professionals should ideally have access to healthcare information at any time or from any place.

With the rapid development of handheld devices, mobile solutions can provide convenient and flexible solutions which would allow healthcare professionals to remotely access healthcare and patients’ information. Healthcare professionals can use mobile appliances, e.g., PDAs, Tablet PCs and smart phones, to access patients’ data remotely. Mobile healthcare services, which can efficiently solve the problems of limited time and space, must be
convenient and flexible for healthcare professionals to use. To provide convenient and flexible mobile healthcare services, this study proposes a novel Seamless Healthcare Information Delivery (SHID). Healthcare professionals would only be required to configure the system initially. Users would then be able to conveniently access desired healthcare information at any time and place, even when traveling between heterogeneous hosts and platforms.

The SHID system is based on the Session Initiation Protocol (SIP) and PUSH technology [17]. Session Initiation Protocol, an application-layer signaling protocol, can be used for establishing, modifying, and terminating multimedia sessions. The encoding formation of SIP is text-based and extended based on Simple Mail Transfer Protocol (SMTP) and Hypertext Transfer Protocol (HTTP). Using PUSH technology, healthcare professionals can access up-to-date healthcare information. Figure 5 depicts the system architecture and control procedure for the SHID system. As shown, SHID system is two-tier and is composed of an end system and an e-healthcare control center (E²C) system. To access the end system, healthcare professionals can use a mobile appliance, e.g., notebook, PDA, or tablet PC, and seamlessly move between different hosts. The control procedure for healthcare professionals reviewing healthcare information on appliance A and then moving to appliance B and appliance C, is described as follows.

**Step 1:** Appliance A sends a register message to Mobility Agent (MA). When MA receives the register message, MA transmits the message to Registrar Server (RS). RS then identifies the validity of the user.
Step 2: If the user is legal, RS sends a “200 OK” message to appliance A.
Step 3: Appliance A request is periodically sent from MA to Database Server (DS) to access the data after the MA receives the “200 OK” message.
Step 4: When the DS receives the request message, the DS returns the requested data to the MA.
Step 5: The MA transmits the data to the current appliance, i.e., appliance A, after receiving the data.
Step 6: The healthcare professionals move from the location of appliance A to the locations of appliance B and C.
Steps 7 and 8: The healthcare professionals move from appliance A to appliance C through appliance B. The related session connections and healthcare information are seamlessly transmitted to appliance B and appliance C.

5. System implementation

The functions of the SPH system are designed for immediate application in any modern hospital. The adopted software and hardware environments are described as follows.

(1) System software: SPH was developed using Java Platform, Standard Edition (J2SE), Micro Edition (J2ME), Eclipse 8.0, MapObject 2.0 and MySQL database.
(2) System hardware: The applied equipments include the vital sign sensor kits, Tablet PC, PDA, IP cameras, wireless microphone/earphones and GPRS module.
Implementing the SPH system includes the Home Healthcare End (HHE) system, the E-healthcare Control Center (ECC) system and the E-healthcare Service Provider (ESP) system.

5.1. Home Healthcare End (HHE) system

Two sensors used in the HHE system are LapPro ECG sensors and Berkeley MOTE sensors [30]. Both sensors include IP cameras. Figure 6 depicts the configuration of a LapPro ECG sensor connected to a MOTE processor board. The transmission unit of the MOTE sensor transmits the sensed healthcare data to Healthcare Engine (HE). Figure 7 depicts the logical network topology of the HHE system. The communication interfaces of the MOTE and video sensors are based on wireless network. Node G is implemented by Stargate [9], which works as the network gateway to aggregate the sensed data from each MOTE sensor.

Node V is the IP video camera located in the healthcare monitoring area. Video distribution is implemented based on the Wireless Distributed System (WDS) and Mobile Ad hoc NETwork [21]. According to Fig. 7, node M, the ECG sensor in conjunction with the MOTE processing sensor detects and collects the physiological data of patients. The sensed physiological data are transmitted to node G, i.e., the Stargate node. Node V also functions as a network gateway, which relays the sensed data and images to Node N, i.e., the network point. The network point is a network connection socket which provides connection interfaces for connecting to HHE and Internet.

5.2. E-healthcare Control Center (ECC) System

Figure 8 depicts the user interface of the ECC system showing the sensed physiological data and patient’s information from the HHE system. Furthermore, the ECC provides the online E-healthcare Service Providers (ESPs), including ESP names, service types, and accounting information. When an abnormal or emergency event occurs, the HHE system establishes a communication session with the appropriate ESP. The ESP can then communicate directly with the patient.

5.3. E-healthcare Service Provider (ESP) System

The ESP system is implemented based on the proposed Context-Aware emergeNcy rEmedy system (CANE) [13]. As a mobile telemedicine system, the CANE system provides a platform by which hospital physicians can communicate with an emergency healthcare technician (EMT) in an ambulance and give appropriate, possibly lifesaving suggestions for treating the patient on the way to the hospital. The CANE system uses Geographic information system (GIS)/Global Positioning System (GPS) technologies to provide location-base services which could help the rescue center to dispatch ambulances more efficiently in response to emergencies.

Figures 9, 10, and 11 depict the procedure used by the CANE system. Figure 9 depicts the ambulance EMT using a PDA to record the patient’s personal information, such as gender, age and symptoms. The EMT immediately transmits the patients’ healthcare records to the hospital to maximize the preparation time available to treat them. Furthermore, if the provision of healthcare records is insufficient to help hospital physicians diagnose the patient, the CANE system includes audiovisual and whiteboard functions so that EMT personnel can show the patient and describe the patient’s photograph using the whiteboard. According to Fig. 10, a physician can easily observe and understand, for example, that a patient’s left elbow is fractured, and then give the appropriate treatment suggestions to EMT personnel.

Figure 11 depicts the GIS/GPS location-aware service for the ambulance driver. The location-aware service provides the ambulance driver with the exact location of an accident or medical emergency and nearby hospitals. In addition, the service provides driving directions, expected arrival time, driving speed, signal strength of satellites, and the longitude and latitude of the vehicle’s current location. During an emergency, the ambulance dispatch center can quickly determine the most appropriate ambulance for rapidly responding by using the functions depicted in Fig. 12. The functions enable dispatchers to quickly determine the location and status of ambulances.
Fig. 6. Illustration of ECG sensor connected to MOTE sensor.

Fig. 7. Network architecture of ECG sensors, MOTE sensors, and video cameras.
6. Conclusions

This paper proposes a Sensor-based Pervasive Healthcare (SPH) System, which is developed to compensate for limitations of the conventional healthcare. The SPH system adopts Wireless Sensor Networks (WSNs) and vital sign sensors to achieve an automatic sensing scheme that can ceaselessly monitor patients’ status including their physiological data and images. Additionally, a Seamless Healthcare Information Delivery (SHID) system is further designed and deployed in an E-healthcare Control Center (ECC) to provide convenient and flexible mobile healthcare services. Based on the SHID system, healthcare professionals can conveniently access the desired healthcare information regardless of their locations even when they are on move between heterogeneous hosts and platforms. The SPH system closely connects the healthcare services with people’s daily lives, and is intended to be used as a mainstream application for future digital healthcare procedures. Using the SPH system, a hospital can trace a patient’s situation on line at any time, and provide information on healthcare to the patient as well as share information and experience with other hospitals. This approach can improve the quality of healthcare treatment given by a hospital and its healthcare professionals, and thus increase the loyalty of a patient to the hospital. To further achieve practical usage in the near future, the implementation of the SPH system is currently being installed in a local teaching hospital to refine and verify the effectiveness of the SPH system.
Fig. 9. Patient healthcare records received by PDA.

Fig. 10. Picture/whiteboard functions.

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Fig. 11. GIS in ambulance.

Fig. 12. Location of ambulances monitored at emergency control center.
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