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Design and Implementation of HL7-based Real-time Data Communication for Mobile Clinical Information System

Jinwook Choi[1], Sooyoung Yoo[1], Heekyong Park[1], Jonghoon Chun[2]

[1]Dept. of Biomedical Engineering, College of Medicine Seoul National University
[2]Division of Computer Engineering, Myongji University
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Abstract: The main obstacles for adopting a mobile health information system to existing hospital information system are the redundancy of clinical data and the additional workload for implementing the new system. To obtain a seamless communication and to reduce the workload of implementation, an easy and simple implementation strategy is required. We propose a mobile clinical information system (MobileMed) which is specially designed for the easy implementation. The key elements of MobileMed are a *smart interface*, an HL7 message server, a central clinical database (CCDB), and a web server. The *smart interface* module transfers the key information to the HL7 message server as new clinical tests data is recorded in the existing laboratory information system. The HL7 message server generates the HL7 messages and sends them to the CCDB. As a central database the CCDB collects the HL7 messages and presents them to the various mobile devices such as PDA. Through this study we might conclude that the architecture for the mobile system will be efficient for real-time data communication, and the specially designed interface will be an easy tool for implementing the mobile clinical information system.

Key words: Hospital information system, HL7, Real-time data communications, PDA

INTRODUCTION

Mobile Computing in Health Care

The ubiquitous access to information anytime, anywhere is quite attractive, but in the medical field, the acceptance of ubiquitous access is challenging. One of the promising ubiquitous computing models is the mobile clinical information system using PDA (personal digital assistant) [1-11]. The ideal of using PDA is to enable doctors to access patient clinical test results from any location, make clinical orders instantly, and send the consultation requests to the specialists with the PDA [12-14].

Among health care professionals, innovations are judged by their direct value for patient care. Clinical systems for diagnosis have been relatively well accepted, sometimes even without any scientific evidence of their actual value. However, clinical information systems that are not directly relevant to the patient care process are less easily accepted [15].

In terms of the patient care process, mobile clinical information systems do not detour the existing process, and should be a good candidate model for assisting the patient care process.

Analysts have predicted that by 2004, 20% of physicians will use handheld devices for e-prescribing, ordering and checking lab tests, capturing charges, and dictating notes [16]. However, what makes the situation complex is not the increase in the number of mobile users, but the complexity of mobile devices. In future, many different devices will be used to access the patient's data in a hospital. Doctors will be able to check clinical information not only just by using their PCs in their offices, but they also will be able to access the data with PDAs, tablet PCs or even by cellular phones while moving around the hospital. Therefore the versatile interface that supports multiple devices will become an essential component of a mobile information system. However, the key challenge is to provide a suitable interface that will exploit the special features of a particular device to offer the appropriate information.

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Corresponding Author: Sooyoung Yoo, Department of Biomedical Engineering, College of Medicine, Seoul National University, 28 Yongon-dong Chongro-gu, Seoul 110-799, Korea
Tel. +82-2-760-3421, Fax. +82-2-745-7870
E-mail: yoosoo0@snu.ac.kr

Data Integration in Medical Environment

With recent movements toward shared clinical data in health care, a number of models, methods, and evaluation strategies have been developed for the integration of clinical data. Data integration, particularly in a medical environment, is the most important issue that must be considered seriously. In 2000, the Institute of Medicine (IOM) in the United States reported that preventable medical errors result in as many as 98,000 deaths each year. This implies that medical errors are the eighth leading cause of death in the U.S., which is almost as high as those caused by motor vehicle accidents (43,000), breast cancer (42,000) and AIDS (17,000) combined [17]. The IOM reported that the decentralized and fragmented status of a health delivery system was the main cause of such medical errors.

The mission of medical informatics is to enable people to use information to improve health care. The integration of data from a variety of sources will also improve the clinical decision making process [18]. In order to understand data communication and the system interoperability among various systems, the HL7 (Health Level 7) has been proposed as a standard for electronic data exchange in medical environments [19].

In this paper, we describe the design and the implementation of mobile clinical information system, called MobileMed, which supports real-time data communications between heterogeneous remote systems and provides web-based data accesses using multiple devices. The HL7 interface to laboratory information system (LIS) is developed for integrating the laboratory test data into our central clinical repository (CCDB) in real-time. And the XML [30,31] technology is adopted to provide a uniform data access to CCDB using various devices. Through the controlled evaluation of the HL7 interface, we showed that the architecture of our system is feasible and efficient enough to apply in real word clinical settings.

BACKGROUND

Considerable research has been directed towards acquiring integrated data, reducing the amount of redundancy, and merging clinical data in the medical arena [20]. In our first stage mobile computing project (MobileNurse™ project), a mobile information system was suggested for nurses. It was a PDA based information system and designed to communicate with hospital information systems via a mobile supporting station which interchanged the clinical data between the mobile system and the HIS [21,22].

The second project (LEX project) [23] proposed a lifelong electronic health record system wherein the clinical document was stored in XML (eXtensible Markup Language) [30,31] after integrating the patient medical data using HL7 messages.

In the LEX project, the polling method was adopted to monitor new data in the legacy hospital information system. With this method, applications asked the legacy system's database for new data that may or may not have been available every scheduled interval times regularly. The hospital information system should be fault tolerant, so the newly developed system should not lower the performance of the legacy hospital information system. Because of the possible deterioration in system performance of the legacy hospital information system, the polling interval was set to no shorter than one minute. The drawbacks of polling are its ineffectiveness. With the timely scheduled polling system, many numbers of polling processes are evoked without binding of real data generation. In order to reduce those meaningless pollings without any data, a new pushing mechanism, in which the event for new data fires only with real data, was designed. This paper describes our new architecture for a mobile clinical information system, in which the number of polling process is minimized so as not to overload the legacy hospital information system and provides an easy implementation interface.

OBJECTIVES

Many technologies have been developed for mobile information systems [24-26]. However, the real challenge of a mobile health care system is to make communication seamless with no time delay between the legacy hospital information systems and the mobile clinical information system. As wireless networks are sometimes unpredictable and long delays can occur due to network traffic, the measures to handle the stability of data exchange should be considered carefully.

The following objectives are considered for the MobileMed in this study.

The data from MobileMed should be easily integrated with an existing clinical database, to allow any information needed to be retrieved on real-time base.

It should provide an easy-to-implement interface so that the health informatics engineers can test and implement the mobile clinical information system in a short period of time.

The design of the interface to the existing clinical database must not affect adversely on its performance.

It should be able to collect new lab test results from the existing clinical database without time delay.

The gathered clinical data must be accessed in a consistent view using any kind of mobile devices.

It must guarantee the reliable data transmission.

It should provide a method reducing the burden of the periodic polling process to the existing clinical database.

SYSTEM DESCRIPTION

Overview of Mobile Clinical Information System

The MobileMed is a PDA based mobile clinical information system that provides a seamless and integrated computing environment in healthcare. It is composed of four key components: a *smart interface* for laboratory information system (LIS), a HL7 message server (HMS), a central clinical database (CCDB), and a web server. The overall architecture of MobileMed is shown in Figure 1.

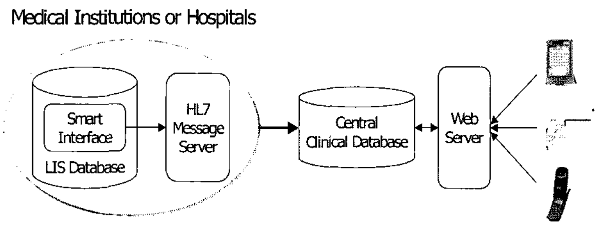

Fig. 1. Overall architecture of MobileMed.

Smart Iinterface for LIS

The *smart interface* is an easy-to-implement application for implementing MobileMed to a legacy hospital information system. The most general hospitals in Korea have developed their own information systems. Because of the information systems of heterogeneous architectures, the implementation of new system always requires an enormous amount of work to interface. In order to reduce the interfacing workload, the HL7 group proposed a messaging standard for the data communication between different systems [19].

For implementing HL7 messaging standard, we designed *smart interface* which is a database-based HL7 interface. The advantages of implementing *smart interface* are as follows:

It can be easily implemented and incorporated into the existing non HL7-based hospital information system. Because it doesn't need any modifications to be made to existing data-intensive client applications in use. Consequently, scalability is guaranteed.

Since we are only interested in a specific laboratory domain and the contents/structures of this information are similar, the development of database programs such as trigger and stored procedure to database system require only minimal changes.

It makes it possible to develop network centric applications using advanced database technologies which can get the database transaction event from the DBMS in real-time.

Using database view we can design the *smart interface* without knowing the physical database structure, which makes it possible to access database with a consistent view.

The *smart interface* is the interface between the existing LIS database and HMS. Its main role is to notify of a specific HL7 trigger event to HMS whenever a new database transaction occurs. Also it provides a consistent and unified data access mechanism.

The *smart interface* consists of two modules: *a set of java stored procedures* [27] and *a message view* as shown in Figure 2. The technology of Java stored procedure is employed in order to transfer database transaction related events to external applications such as HMS in real-time. The main benefits of the Java stored procedure are the popularity regardless of the computing environment, the easy portability, and safety. Using a Java stored procedure language, the code will be transferred easily to the servers of different vendors [28,29]. We designed two kinds of java stored procedures, *XML wrapper* and *event sender*, which have the following functions.

The *XML wrapper* is the first acting Java stored procedure which is invoked by a database trigger. It creates XML formatted ASCII text on the basis of the value of its parameters. The benefit of using XML encoded data is its easy interoperability between diverse formats. In MobileMed, the XML data contains a set of key information such as the event type of data insertion, the patient's ID, the time of insertion, and the service/observation code. The output of the XML wrapper is delivered to the *event sender*, which controls the flows of the XML data.

The *event sender* is responsible for the real-time data communication between the LIS database and the HMS. It sends XML strings from the *XML wrapper* to the HMS via a TCP socket. In addition, it verifies the transmission by checking the received acknowledgement from the HMS in order to provide reliable communication without data loss or failure. If the socket connection fails to receive any success acknowledgement from the HMS, it regards the connection status as a transient failure of the data communication and sends them into an event_log table, which is designed to keep the data temporarily until the connection is re-established.

The *message view* provides unifying view [41]. It contains all data needed for encoding a specific v2.x HL7 messages. The following three views are created for the ORU (Observation Report – Unsolicited) message: 1) the view for the patient demographics, which will be used as the PID (patient identification) segment; 2) the view for the ordered clinical lab tests; and 3) the view for the clinical lab test results, which will be used as the OBX segment.

HL7 Message Server

On the insertion of new clinical lab test to LIS, the *smart interface* transfers the occurred HL7 trigger event and related key information to the HL7 message server (HMS). The HMS generates the appropriate HL7 messages [32] and sends them to the CCDB. The HMS communicates with the LIS database through two channels of the event channel and data channel. (Figure 2) Through the event channel, the HMS receives the event notification in the XML format, which contains the information on the triggered HL7 events, the patient ID, and the time-stamp of the event. The data channel is responsible for the real data communication, and loading the complete data needed for a specific HL7 message from the LIS database.

Modules in the HMS function are as follows:

The *event manager* receives HL7 event notification encoded in XML from the *smart interface.* Then according to the event type, it classifies the incoming events into the appropriate event queue by using DOM parser [33]. It then activates the *HL7 transformer* using its timer to generate the message. We employed a timer to set the actual time of message creation to add flexibility to the deployment environment.

The *HL7 transformer* automatically generates HL7 messages using each element of the event queue. Upon the notification of a new HL7 trigger event, the *HL7 transformer* requests the *data loader* to fetch the relevant data from the *message view.* Then it automatically generates the appropriate HL7 messages using pre-defined mapping functions.

The *message sender* communicates with the CCDB upon the TCP/IP protocol. After it transfers the HL7 messages to the CCDB, it receives their acknowledgement messages in order to verify the successful transmission.

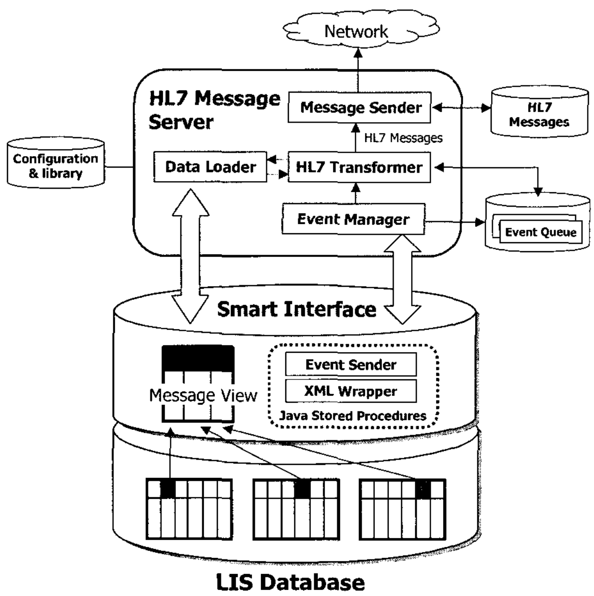

Fig. 2. Architecture of the HL7 message server.

Central Clinical Database

The Central Clinical Database (CCDB) is a central repository that contains the integrated clinical information for a mobile clinical information system. The main purpose of the CCDB is to eliminate the retrieving workload of the operating system, which can be caused by the mobile system, and to integrate the clinical data. By directing all the data retrieval requests to the CCDB, it minimizes the retrieving workload of the legacy hospital information system. The front-end HL7 interface to CCDB receives the HL7 messages from the HMS and extracts the clinical lab test results from the HL7 messages and stores the data into the CCDB. Despite the redundancy to acquire all the necessary information at one access, the CCDB also contains the basic information of the patients and assigned clinicians.

As shown in Figure 1, the CCDB collects all the clinical lab test results from the various information systems and presents the data to mobile devices through the web. Logically, the database schema is composed of three main parts of the patient's information, clinical data, and other master data.

Web Server

Figure 3 shows the architecture of web server for the versatile presentation, which means that the display format can be altered according to the user devices. A web-based architecture enabled with XML translation was designed in order to support a device dependent interface. When clinicians request the clinical data by mobile devices, the *profile manager* of the web server first catches the user profile [34-36] in order to narrow down the searching scope of the CCDB. At the same time it also acquires the device profile to fit a display screen to the requesting device.

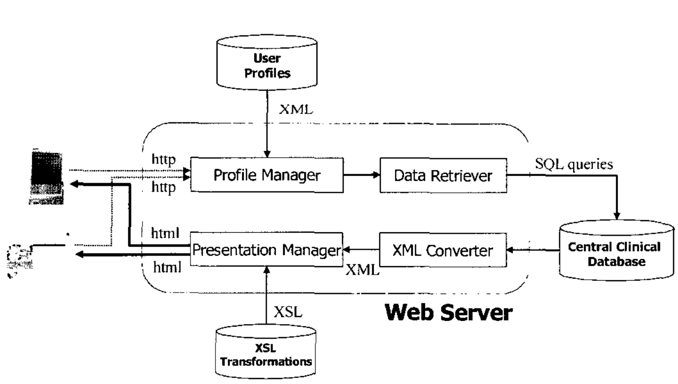

Fig. 3. Architecture of the web server.

The *data retriever* in the web server performs the database query on the CCDB, and the result is sent to the *XML converter*. In order to fit the displaying window to the individual devices, the XML is sent to the *presentation manager*. This converts the XML to HTML by referring to the appropriate XSLT (XML Stylesheet Transformations Language) [37], which holds the displaying format of the various output devices [38].

STATUS REPORT

The described system is a prototype that was developed over 2 years. In order to evaluate the MobileMed, the test bed LIS database, which had a similar architecture of legacy hospital information system, was developed using Oracle 9i DBMS. The LIS database was filled with clinical lab test data up to the 10, 000 patients data set. In our test bed, six types of clinical battery tests were designed to be sent to the CCDB from the LIS database. The data in the LIS database was gathered into the CCDB using the HL7 messages.

The HMS is implemented using Microsoft Visual Basic 6.0 and Symphona™ library on a Windows 2000 Server. Figure 4 shows the user interface used for monitoring its operation. Each of the three sections of Figure 4 displays sent messages, sending messages, received acknowledgement messages. We measured the performance of the HMS, in terms of scalability, by calculating the elapsed time with millisecond (ms) precision from the insertion time of new data into the LIS database to HL7 message completion time. In order to remove the possible network delay time, we deployed the LIS database and the HMS on the same machine. We assumed that a single row of data insertion into the HL7 database makes the HMS generate one HL7 message due to variations of the number of observations in the battery tests, although our system can automatically detect each battery test and generate a single message for a certain number of rows have accumulated. We measured the elapsed time by increasing the number of data insertions for an hour starting from 1,000 to 5,000 with 1,000 increments. Figure 5 shows the average results after we performed each test on different test environments. The computer 1 has Intel Pentium IV 3.2 GHz with 1 GB main memory and 200 GB disk. The computer 2 has Intel Xeon Dual chips of 2.66 GHz with 2 GB main memory and 320 GB disk. As shown in the Figure 5, the average time for generating a message is almost constant whenever data occur very frequently. And the average time is reduced to over seven times in the dual processor computer environment. Although 10,000 data was issued during one hour, we observed that a message was generated within average 0.071 second. We also noted that because the evaluation was performed in a constrained test environment, the performance would be greatly improved if we measured the elapsed time for a single battery test as our system actually was designed.

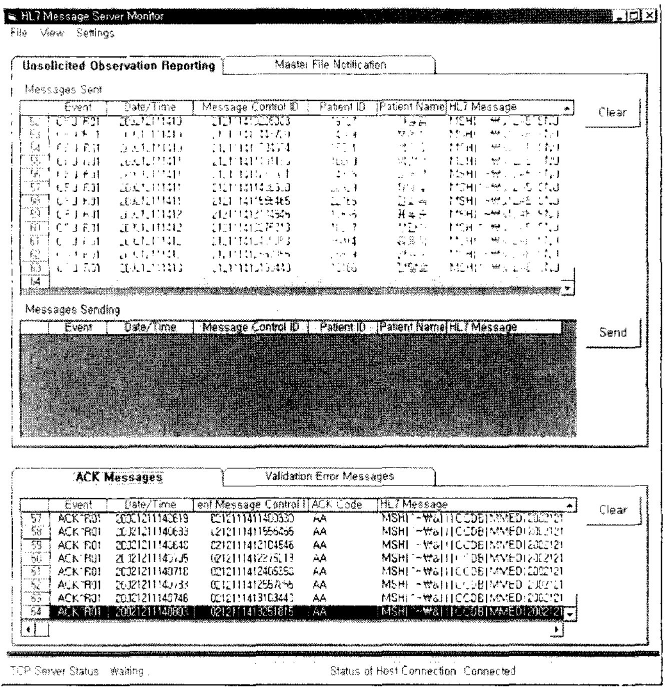

Fig. 4. Screen shot of the HL7 message server monitoring module. The monitoring module shows HL7 messages sent in upper window, in the bottom window it shows the acknowledge messages received.

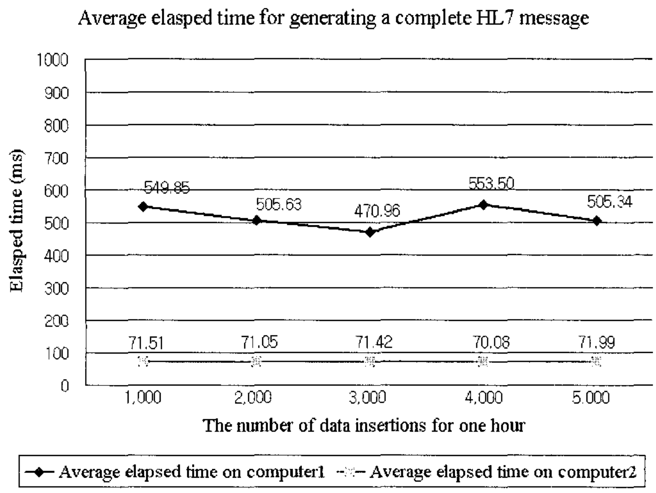

Fig. 5. Performance test results showing average elapsed time for generating HL7 messages.

Figure 6 shows a typical view of the MobileMed user interfaces that is implemented using JSP, oracle XML parser. With the input of the user ID and password, the MobileMed creates a user profile to limit the primary searching scope. After selecting the patient assigned to the clinician, MobileMed shows the relevant clinical data in the time sequence. The clinical data is displayed with the normal values next to the clinical data, and MobileMed also provides a button for the cumulative view of the selected data. With a tapping of the cumulative button, MobileMed shows the whole collection of the data for up to 3 months immediately.

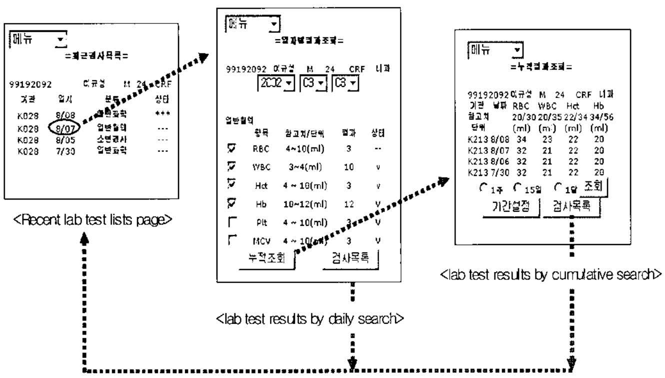

Fig. 6. Screen shots of the MobileMed user interface running on an emulator of PDA for selecting patient lab test results.

In order to support device dependent display, the *presentation manager* translates the XML data into HTML by referring to the XSL. At the initial query for the data, the web browser of the user device sends the device information such as 'Mozillar' for the desktop computer [39], 'Cellvic' [40] for the PDA used for this project or 'Mozilla/2.0 (compatible; MSIE 3.02; Windows CE; 440x320)' for other types of PDAs. Using the displaying device information, the *presentation manager* fits the displaying window by referring to the relevant XSLs. Figure 7 shows the user screens of the desktop computer and PDAs.

The main advantages of the MobileMed are its simple and easy interface as well as its ability to minimize the system burden. In our previous projects, a time scheduled polling system was evoked regularly to check the new data in the LIS database. We experienced the overload of the legacy hospital information system when the polling interval was set to less than 1 minute. In order to lessen system burden the event push method is proposed to notify the new data of the LIS database. With this method, only the new data insertion evokes the database trigger which notifies the clinician of new data. The HMS responds only to the generation of real data, which reduces the overall system load for monitoring new data.

Inside the LIS database, the *smart interface* layer, which allows the interface engineers to implement MobileMed easily, is implemented. The *message view* of the *smart interface* is a virtual table that is meant to fetch all the required elements from the LIS database. The mapping between the existing LIS database and the *message view* is the only work that needs to be done by the interface engineers. In order to provide flexible management, a procedural meta table for a *smart interface*, which contains the mapping functions for building various HL7 segments, is designed.

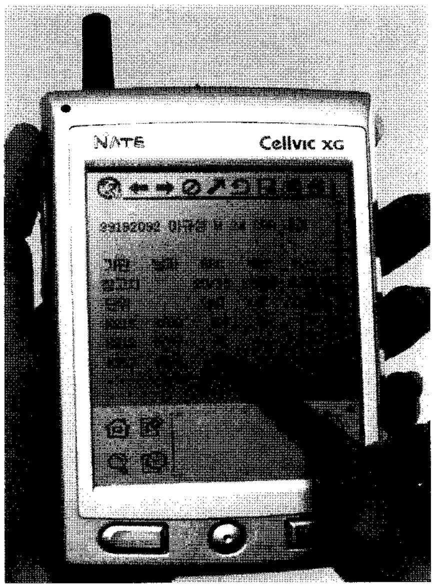

Fig. 7. User screens of MobileMed from PDA (left) and desktop computer (right).

CONCLUSIONS

This paper presents a mobile clinical information system, MobileMed, which integrates the distributed patient clinical data using a smart interface and advanced database technologies. A set of modules written in Java is implemented in order to achieve seamless integration and easy portability. Using the XML technology, any data on the central clinical database can be accessed with the user-friendly display format.

This system represents a potential model for the PDA based mobile computing in health care, where the patient's clinical data can be easily shared among clinicians and can be easily accessed anywhere. Future work will aim to solve the semantic between various systems.

REFERENCES

[1] D.J. Cada, *"PDAs: Medical Information in the palm of your hand"*, Hospital Pharmacy, Vol. 34, p.639, 1999.

[2] J.I. Roller, P.R. Zimnik, D.E. Calcagni, and E.R. Gomes, *"Project Promed: the development of a wireless hospital-based network utilizing personal digital assistants"*, Paper presented to the 34th Annual Meeting of the Armed Forces District, The American College of Obstetricians and Gynecologists. San Diego, Calif., 2-6 October, 1995.

[3] R.M. Satava, *"Virtual reality and telepresence for military medicine"*, Ann. Acad. Med. Singapore, Vol. 26, pp.18-20, 1997.

[4] J. Blackman, P. Gorman, R. Lohensohn, D. Kreamer, and S. Svingen, *"The usefulness of Handheld Computers in a Surgical Group Practice"*, Proc. AMIA Symp., pp.686-690, 1999.

[5] M. Cushing, *"The data entry conundrum"*, MD Comput., Vol. 12, pp.259-261, 1995.

[6] J.S. Hammer, J.J. Strâin, A. Friedberg, and G. Fulop, *"Operationalizing a bedside pen entry notebook clinical database system in consultation-liasonliaison psychiatry"*, Gen. Hosp. Psychiatry, Vol. 17, pp.165-175, 1995.

[7] S. Shea, R.V. Sideli, W. DuMouchel, G. Pulver, R.R. Arons, and P.D. Clayton, *"Computer-generated informational messages directed to physicians: effect on length of hospital stay"*, J. Am. Med. Inform. Assoc., Vol. 2, pp.58-64, 1995.

[8] R.D. Acuff, L. M. Fagan, T.C. Rindfleisch, B.J. Levitt, and P.M. Ford, *"Lightweight, mobile e-mail for intra-clinic communication"*, Proc. AMIA Annu. Fall Symp., pp.729-733, 1997.

[9] A. Malek, N. Coblio, M. McCormick, and W.S. Harris, *"Use of wireless communication by handheld pen-based computers to cut medical costs and improve health care"*, Proc. AMIA Annu. Fall Symp., 1997.

[10] N.M Hasset, and M.H. Farver, Information management in home care, In: Nursing Informatics: Where caring and technology Meet, M.J. Ball Ed., New York: Springer-Verlag, pp.155-166, 1995.

[11] M. Ancona, G. Dodero, F. Minuto, M. Guida, and V. Gianuzzi, *"Mobile computing in a hospital: the WARD-IN-HAND project"*, Proc. 2000 ACM Symp. on Applied computing, pp.554-556, 2000.

[12] S. Fischer, T.E. Steward, S. Mehta, R. Wax, and S.E. Lapinsky, *"Hanheld Computing in Medicine"*, J. Am. Med. Inform. Assoc., Vol. 10, pp.139-149, 2003.

[13] M.H. Ebell, D.L. Gaspar, and S. Khurana, *"Family physicians' preference for computerized decision-support hardware and software"*, J. Fam. Pract., Vol. 45, pp.127-128, 1997.

[14] M. Greiver, *"Evidence-based medicine at the palm of your hand"*, Can. Med. Assoc. J., Vol. 164, p.250, 2001.

[15] H.D. Banta. Embracing or rejecting innovations: clinical diffusion of health care technology, In: Use and impact of computers in clinical medicine, Anderson JG, Jay SJ Ed., New York: Springer Verlag, 1987.

[16] J. Fisher, and R. Wang, The cure is in Hand, market report from WR Hambrecht and Co, 2000.

[17] R.E Rouse, and J.S. Charlson, The evolution of eHealth, Lehman Brothers report, 2000.

[18] W.W. Stead, R.A. Miller, M.A. Musen, and W.R. Hersh, *"Integration and beyond: linking information from disparate sources and into workflow"*, J. Am. Med. Inform. Assoc., Vol. 7, pp.135-145, 2000.

[19] Health level seven standards, http://www.hl7.org/.

[20] A. Riva, K.D. Mandl, D.H. Oh, D.J. Nigrin, A. Butte, P. Szolovits, and I.S. Kohane, *"The Personal Internetworked Notary and Guardian"*, Int. J. Med. Inf., Vol. 62, pp.27-40, 2001.

[21] S.K. Hyun, J.W. Choi, J.H. Chun, S.G. Lee, D.H. Shin, D.H. Kim, and D.G. Kim, *"Implementation of Mobile Computing System in Clinical Environment: MobileNurse"*, Proc. AMIA Annu. Fall Symp., 2000.

[22] S.K. Hyun, J.W. Choi, J.H. Chun, S.G. Lee, D.H. Shin, D.H. Kim, and D.G. Kim, *"Developing a Mobile Nursing Information System for Clinical Environment: MobileNurse™"*, Proc. CJKMI, 2000.

[23] S.Y. Yoo, B.Y. Kim, S.B. Han, J.W. Choi, J.H. Jung, M.K. Min, J.H. Chun, *"Design and Evaluation of a Prototype of HL7 Message Server for Information Sharing among Medical Institutions"*, Journal of Korean Society of Medical Informatics, Vol. 7, pp.1-8, 2000.

[24] K. Lyytinen, and Y.G. Yoo, *"Issues and Challenges in Ubiquitous Computing"*, Communications of the ACM, Vol. 45, pp.63-65, 2002.

[25] G.B. Davis, *"Anytime/Anyplace Computing and the Future of Knowledge Work"*, Communications of the ACM, Vol. 45, pp.67-73, 2002.

[26] G. Banavar, and A. Bernstein, *"Software Infrastructure and Design Challenges for Ubiquitous Computing Applications"*, Communications of the ACM, Vol. 45, pp.92-96, 2002.

[27] M. Awal, M. Bortniker, J. Carnell, K. Cox, D. O'Connor, M. Zucca, S. Dillon, T. Kyte, A. Horton, F. Hubeny, G.E. Mitchell, K. Mukhar, G. Nicol, and G.R. Hammond, Professional Oracle 8i Application Programming with Java, PL/SQL and XML, USA: Wrox Press, 2000.

[28] Oracle Technology Network, http://otn.oracle.com/.

[29] http://www.firstsql.com/.

[30] W3C (2000) Extensible markup language (XML) 1.0, 2nd edn. http://www.w3.org/TR/REC-xml/.

[31] E.R. Harold, XML Bible, USA: IDG Books, 1999.

[32] HL7 V2.3.1 Standard Specification, Chapter 7.

[33] W3C (2002) Document object model (DOM) level 1 specification (2nd edn), Version 1.0. http://www.w3.org/TR/REC-DOM-Level-1/.

[34] F. Liu, C. Yu, and W. Meng, Personalized web search by mapping user queries to categories, Proceedings of the eleventh international conference on Information and knowledge management, pp.558-565, 2002.

[35] L. Suryanarayana, and J. Hjelm, Ubiquitous WWW: Profiles for the situated web, Proceedings of the eleventh international conference on World Wide Web, pp.200-209, 2002.

[36] WAG User Agent Profile Specifications, WAP 2.0 Version, 10/2001. http://www1.wapforum.org/tech/documents/WAP-248-UAProf-20011020-a.pdf.

[37] W3C (1999) XSL Transformations 1.0. http://www.w3.org/TR/xslt.

[38] S. Muench, Building Oracle XML Applications, USA: Oreilly & Associates, 2000.

[39] S. Allamaraju, A. Longshaw, D. O'Connor, G.V. Huizen, J. Diamond, J. Griffin, M. Holden, M. Deley, M. Wilcox, and R. Browett, Professional Java Server Programming J2EE Edition, USA: Wrox Press, 2000

[40] Cellvic web site. http://www.cellivic.com/.

[41] S.Y. Yoo, B.Y. Kim, H.K. Park, J.W. Choi, J.H. Jung, J.H. Chun, Y.H. Yoon, *"Design and Implementation of View Based HL7 Interface for Heterogeneous LIS Databases"*, Proceedings of 18th KOSMI Spring Congresses, p.222, 2002.