ORIGINAL RESEARCH

WISH: A Wireless Mobile Multimedia Information System in Healthcare Using RFID

Weider D. Yu, Ph.D.,[1] Pradeep Ray, Ph.D.,[2] and Tiberiu Motoc, M.S.[1]

[1]Computer Engineering Department, College of Engineering, San Jose State University, San Jose, California.
[2]School of Information Systems, Technology and Management, University of New South Wales, Sydney, NSW, Australia.

Abstract

It is important to improve the efficiency of healthcare-related operations and the associated costs. Healthcare organizations are constantly under increased pressure to streamline operations and provide enhanced services to their patients. Wireless mobile computing technology has the potential to provide the desired benefits and would be a critical part of today's healthcare information system. In this paper, a system is presented to better facilitate the functions of physicians and medical staff in healthcare by using modern wireless mobile technology, Radio Frequency Identification (RFID) tools, and multimedia streaming. The paper includes a case study of the development of such a system in the context of healthcare in the United States. The results of the study show how wireless mobile multimedia systems can be developed for the improvement of the quality and efficiency in healthcare for other nations as well. Our testing data show a time reduction of more than 50% in the daily activities of hospital staff.

Key words: *wireless mobile computing, Radio Frequency Identification, Wireless Mobile Information Systems for Healthcare*

Introduction

With mobile devices and wireless technology, healthcare practitioners can have ubiquitous access to critical medical and patient information. The availability of mobile wireless devices will enable medical information to be available at the right place and at the right time. Also, integrated cameras with mobile devices enable physicians to examine patients remotely. This paper presents the design and development of a wireless mobile multimedia solutions system for healthcare based on Radio Frequency Identification (RFID) tags and Pocket PCs.[1,2] The system is called Wireless Mobile Information Systems for Healthcare (WISH).

WISH replaces the traditional paper files with electronic records.[3] It allows medical staff members to record patient information at the point of care and provides access to patient data anywhere at anytime. Thus, it helps to reduce clinical human errors such as incorrect drug administration. Moreover, patient data are available as soon as they are recorded into the system for all the medical staff. This improves the productivity of physicians and medical staff.

The paper starts with an introduction of the application of RFID[4] and mobile multimedia technologies in healthcare.[5] This is followed by related background and healthcare issues encountered today, the system design methodology used and functionalities built in the WISH system, and a risk factor analysis and management issues when the system is used. We then discuss some results of simulation testing conducted. The paper concludes with a summary of the work discussed and future work.

Background of Healthcare-Related Issues

Healthcare practices and the technologies used have made good progress. However, some major issues exist and they need to have better solutions in higher quality and performance and lower cost to healthcare providers and consumers.

1. Need of Electronic Healthcare Records System: An Electronic Health Record (EHR) plays the crucial role of aggregating health information about a patient from diverse technological platforms, information sources, and medical procedures.[6] Mobile multimedia technologies can play an important role in making

DOI: 10.1089/tmj.2007.0057

EHR information available to physicians and patients at the right place and right time.
2. Cost Reduction: In addition to addressing the need to avoid paper inside hospitals, healthcare information technologies (IT) will allow hospitals to reduce their healthcare costs.[3] John Chambers, CEO of Cisco Systems, says that technology could cut healthcare costs by at least 25%. Secretary Thompson estimates that the United States could save at least $140 billion per year by using more IT.
3. Medical Errors Reduction: More important than cost reduction, healthcare IT can improve healthcare by avoiding medical errors. Medical error is one of the largest causes of death in the United States.[7] Studies from the Institute of Medicine showed that medical errors are responsible for 44,000 to 98,000 American deaths a year in U.S. hospitals. The use of IT systems by physicians not only replaces the traditional folder, but the systems can also alert nurses if the wrong medication is administered to a patient.
4. Healthcare IT Target Domains: For a few hospitals that use IT, the main domains of use are business management (as an enterprise), devices and room management (location), file management, surgery care, and patient care (physicians, nurses, bedside workflow). However, the most developed domains are business management, medical devices, and surgery care, whereas systems for bedside workflow and file management are very rare.

Areas of Study Design

Project WISH proposes to build a distributed application with the objective to improve healthcare in hospitals. The application will allow physicians and nurses to complete patient bedside workflow via smart devices. In addition, the RFID technology is used to automatically display the patient's medical file when the clinician is in the proximity of the patient.[8,9] The smart device client is available wirelessly via a Wi-Fi network but is also able to complete data access and processes offline.[10,11] A synchronization process keeps the devices and the main server database up to date. The application is also accessible from a traditional Web client via the Internet.

The proposed solution recognizes different roles within a hospital system (physician, nurse, secretary, patient) and assigns functionalities to the roles accordingly. For example, a nurse has access to patient information, but the nurse is not allowed to schedule patient appointments. A physician does have access to patient information and he/she is also allowed to schedule patient appointments. More information about roles and functionalities is described in the following sections.

The smart devices used in the proposed solution are the Tablet PC, the Pocket PC, and the eBox II (a System-on-Chip thin client from DMP Electronics Inc.). The technologies assigned for each role are based on the role's responsibilities, work habits and patterns, and budget considerations. It should be noted that roles are not restricted to technology (e.g., a nurse can use a Tablet PC to fulfill his/her daily activities); the role-technology relationships here are suggestions on how the proposed solution can be implemented in a hospital system.

Tiered System Design Methodology and System Analysis

By allowing the availability of information from any physical location, the system increases efficiency and productivity. The information is automatic, thus reducing the number of errors in the workflow. The WISH solution has two wireless components: the wireless communication system, which enables smart devices and server to exchange information and make it available for use, and the wireless identification system, which the RFID technology that uniquely identifies objects and people is part of. The two wireless components are independent of each other, because they implement different functionalities of the proposed solution and are based on different technologies. The wireless communication system is based on smart devices and Wi-Fi networking as well as on a solid architecture that implements services of security, reliability, availability, and maintainability. It allows the medical staff to access patient profiles without being bound to a physical location. The identity of the patients is retrieved via the wireless identification system, which is based on RFID technology.

SYSTEM ARCHITECTURAL DESIGN

1. Service-based architecture design. The architecture proposed for the wireless communication system is a service-based solution. Because of the wireless nature of the application, devices can become disconnected from the network. These "occasionally connected smart clients" must allow the medical staff to be productive with their application even when they are offline and still provide the full functionality of the application when they are connected to the network. This can be achieved by looking at the mobile devices as autonomous components that interact with each other by exchanging messages. Each component is organized as a traditional n-tier application, in which components at a certain level use the services provided by the lower levels and provide functionality to services on the upper levels. This type of architecture is known in the distributed application design as a service-based solution (*Fig. 1*). Each of the four devices (Pocket PC, Tablet PC, eBox II, and Server) is a component in the system, some with more tiers than others. The central component is an application server that exposes the system's functionalities as Web services that the client devices consume.

Generally speaking, the central component is a server and it is designed and organized into three tiers: Presentation Tier, Business Logic (BL) Tier, and Database Access (DA) Tier. The Presentation Tier provides Graphical User Interface information to the users of the system. The BL Tier consists of various healthcare business-related functions and decision processes. The DA Tier manages and accesses the system's central database. The client devices do not directly interact with each other. The central database contains the patient information and can only be accessed via the application server (through its interfaces). The client device, such as Tablet PC or eBox II, also has the same kind of three-tier system design and its DA Tier interfaces a local database. The Pocket PC client functions as a thin client and is designed as a two-tier (Presentation Tier and BL Tier) component.

When designing a distributed application, it is necessary to look at the logical and physical architecture of the components and of the overall system as well as to define the technologies and the infrastructure supporting the system. We will analyze the four devices (Pocket PC, Tablet PC, eBox II, and Desktop) used by the medical staff, the application server, and the central database, as components of the service-based solution describing their logical design. The next few sections will also address the communication system design. Throughout the discussion, we will address the issues of security (such as authentication and authorization),[12] availability, performance, scalability and manageability. The RFID portion of the system will be described as a stand-alone component.

2. Tablet PC and eBox II. The Tablet PC and the eBox II applications follow similar architectures, but have different implementations. The Tablet PC runs Microsoft Windows XP Tablet PC Edition (Microsoft, Redmond, WA), and therefore can take advantage of the rich set of classes provided by the Microsoft .NET Framework Library. The eBox II is an embedded device, running on a simplified computer architecture; it is running Windows CE 5.0 and can only use the Microsoft .NET Compact Framework classes. The advantages of using the eBox II in the proposed solution (compared to the Tablet PC) are price and size, but it comes at the cost of lower processing power.

The patient profile search is first run on the device's local database and displayed accordingly; if not found, then the patient profile search is run on the central database by synchronizing with the main application server (given connectivity). Synchronization with the main application server is also done whenever the device is connected to the network, following a predefined synchronization algorithm.

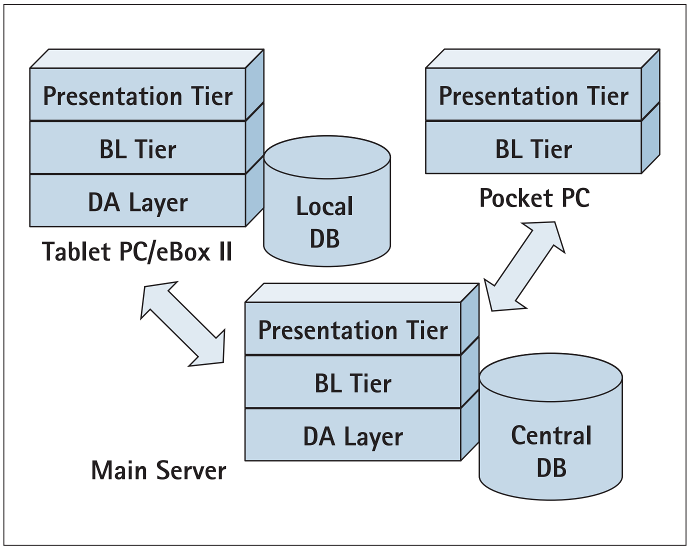

Fig. 1. Service-base architecture. DA, Database Access; DB, Data Base; BL, Business Logic.

3. Pocket PC. The Pocket PC could have been designed to follow the service-oriented architecture of the Tablet PC and eBox II design that includes a local database. Just like the eBox II, it provides more functionality than a simple thin client application.[13] However, it does not have the processing power of the eBox II and would yield low performance as a service-oriented application. More server synchronization would be required, thus impacting the availability of the system. The Pocket PC acts like a thin client, allowing the user to login and perform patient profile lookups (directly on the main server via services). This application depends completely on the network connectivity, without having any local caching capabilities.

This device follows a data-centric architecture, comprising only of user interface and service agents through which it consumes the server's service interfaces.

4. Desktop. The server application is a traditional Web page that exposes the full functionality of the system. All features are available 24/7 on the desktop application because it accesses a Web (Forms) application that runs directly on the main server. The server application is described as the user interface components layer in the main server's architecture (described next).

5. Main server. A traditional three-tier design is employed in architecting the main server application. The advantages of using a three-tier design are numerous; such a system provides scalability, maintainability, and overall flexibility. The main server application exposes all the functionalities of the system through Web services—accessed by the smart clients, and through the Web application—accessed by the browser. It authenticates and authorizes clients, services client requests (e.g., find a specific patient profile), and performs client synchronization.

The design includes user interface components and user interface process components (first tier) that provide a way for the medical staff to interact with the system via a desktop Web browser. The second tier contains business entities and business components that implement the business rules and perform business tasks, such as authentication and authorization of users. The third tier, the data access layer, centralizes data access functionality. *Figure 2* shows the details of the main server application design and the communication system with the smart devices.[13]

6. Communication infrastructure. In a service-based architecture, services communicate to each other by passing messages. In the proposed solution, messages will be passed wirelessly over a Wi-Fi network using 802.11. The Wi-Fi network connects the smart devices and the main server through the multiple access points spread throughout the medical center. To protect against security attacks, the Wi-Fi network employs the Wi-Fi Protected Access (WPA) standard as its encryption standard.

7. RFID module. The RFID module provides the second wireless service in the proposed solution. Similar to how the wireless network and the communication between the devices provided wireless connectivity and information sharing, this module provides wireless identification. It allows the correct identification of a patient from a distance in an automated fashion.

The RFID module is the layer that sits in between the Tablet PC and the eBox II applications and the underlying operating system. The device driver is actually part of a .NET SDK (Software Development Kit) project developed at San Jose State University. The TIS2000 SDK provides a serial port device driver and layers of availability, security, and reliability for the implementing application. The SDK is highly configurable and provides options for adapting the RFID reader to operate in the medical environment (e.g., adjust power burst rates to increase/decrease transponder readability and decrease/increase the read radius).

8. Multimedia communication. The system uses camera and speakers to perform video and audio streaming functions. Audio and video files can be downloaded and played on the client devices, such as patient's photo and patient's special physical status.

WISH SYSTEM OVERVIEW AND ANALYSIS

In this section, the major roles involved in using the WISH system in a hospital, the main system functionalities, and some risk factors and management issues are described.

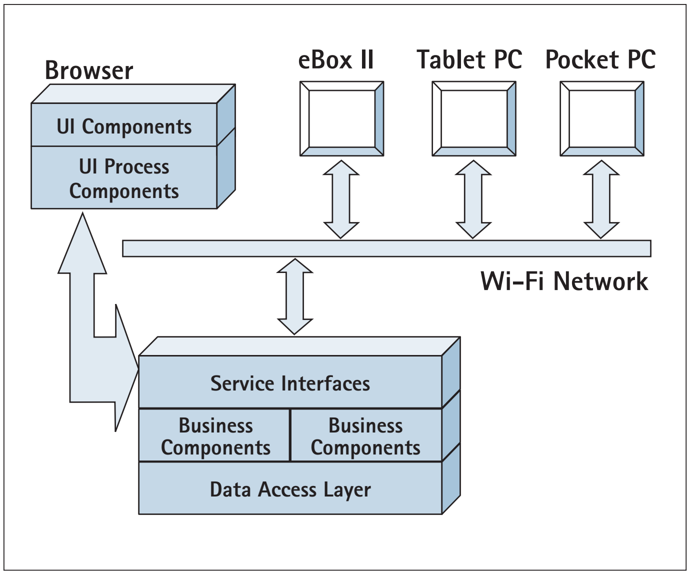

Fig. 2. Main server architecture and device communication. UI, user interface.

Major roles. The following major roles defined in the WISH system are described below.

1. *Physician.* An authorized physician can access the system through a Tablet PC, Pocket PC, or a computer. WISH assists physicians during their patient visits. It also provides an easier way to manage their patient files and allows a quick access to a knowledge base of old medical cases and to view a patient's multimedia streaming data files.
2. *Nurse.* A registered and authorized nurse can access the system through an eBox II system, a Tablet PC, a Pocket PC, or a computer. The system provides functions to assist the nurses in managing the patient data and in recording the patient aftercare data, such as temperature and blood pressure. WISH makes the data available for physicians as soon as the data are recorded by the nurse. The data include patient database data and audio/video streams. The nurse can decide whether producing a multimedia file is helpful for physicians to understand the actual conditions of a patient.
3. *Secretary.* An authorized secretary can only access the system through a computer that has a network or Internet access. The role of a secretary is to manage the patient files and to help the physicians to record and update patient information.
4. *Patient.* A legally admitted patient can only access the system through a computer that has a network or an Internet access.

They are restricted to functions such as consulting their own files and accessing the medical staff contact information.

5. *System administrator.* The system administrator is responsible for WISH system user management. The administrator creates, modifies, or deletes the user accounts and maintains the physicians, nurses, and secretaries information.

System functions and analysis. This section describes and analyzes all the functions available in the WISH system.

1. *Central and local database synchronization.* This function is available on the Tablet PC and eBox II clients, and it is used by a physician or nurse role. The user of the device can download the database information from the centralized database directly on his/her Tablet PC or eBox II. This download function overwrites the current database in the device. The user can also upload the local database information into the main database when all local modifications are completed.
2. *Patient file creation, modification, and deletion.* This function is available on the traditional Web client only for a secretary role. The secretary can create or delete a patient file. As soon as a patient's file is created, it is available online for access. While a new patient file is created, a patient user account and a RFID number are assigned to the patient. A nurse or physician can create an audio/video multimedia streaming file about patient's condition.
3. *Patient file consultation and editing.* This function is used by a physician, nurse, secretary, or patient role. A patient file can be fetched and consulted during a patient's information research session. The file can be automatically downloaded on the Tablet PC using the RFID technology, or temporarily stored on the Pocket PC. The data used in the files can be accessed from either the main database or from the local database (in the case of the Tablet PC and eBox II, even when these devices are offline). Each role can only access the patient files with access permissions. A physician can access his/her patients' files, a secretary can access all the patient files of his/her supervising physician, and the nurse can access the patient files for the patients under his/her medical care service. In general, the policy of role-based access control is applied to determine which roles can access or modify which patient files.
4. *Patient file research and investigation.* This function is used by a physician, nurse, or secretary role. When the research is complete, the user can choose one of the available research results and see the corresponding patient file according to the access control rules.
5. *Medical case research.* This function is used by a physician, nurse, and secretary role. The research is always done on the centralized server. That means that it cannot be done from a mobile device that is offline. The research is done by the medical case's name and date. The user enters a name and chooses a time period to limit the research (e.g., medical cases of this year only). When the research is complete, the user can choose one of the available results and see the corresponding medical case files.
6. *Medical staff file research.* This function is used by a physician or nurse role. The research is always done on the main database server. That means that it cannot be done from a mobile device that is offline. The research is done by the medical staff's name or the patient's name. The research by patient name allows the user to see the medical staff members related to the corresponding patient. Consequently, because of medical confidentiality, the research by patient name is not accessible to patients.
7. *Medical staff file and user account management.* This function is available on the Web client for an administrator role only. An administrator of the system can add, delete, and modify medical staff member information. He/she can also create user accounts and assign roles.

RISKS ANALYSIS AND MANAGEMENT

Because the system is intended for the hospital environment, some risk factors are taken into consideration.

Multilevel security protection. The security concern for patient medical information confidentiality is crucial. Patient records should not be accessed by an unauthorized person. Consequently, an authentication system is absolutely necessary in this application. Various solutions can be considered such as login/password, signature recognition, or fingerprints recognition.

We decided to implement the login/password system for all clients, because it is easy to implement, convenient in use, and secure enough. To further strengthen the security protection, we implemented a second-level authentication system on the mobile devices (eBox II, Tablet PC, and Pocket PC). The staff members should also be identifiable via RFID (each would carry an RFID-embedded wristband just like the patients), using their RFID tags to log onto the system. The RFID number must correspond to the login and password for the authentication to be confirmed. The signature recognition system will be incorporated into the system in the future to increase another layer of security in authentication and authorization.

System and information availability. The second risk concerns the availability of the system and its crucial information. The system contains and displays vital information for the physicians and the nurses. If the database or the server is down, the users must have the capability to access the information and continue their jobs or operations. A regular database backup and recovery procedure is provided to have patients' data automatically backed up and restored on the main database sever as well as on the local databases on client devices used by nurses and physicians. In case the main server is down, the nurses and physicians still can access patient's data via the local databases on their client devices. The system can be switched over to a redundant (or dual) server when the main sever is not available.

RFID security considerations. The use of RFIDs introduces a new set of risks. The reader emits electromagnetic signals that power up transponders in its vicinity; the transponders reply their bit signatures by backscattering the carrier signal from the reader. Every sequence in the communication protocol can fail under external attack. A reader cannot detect the reading of a cloned transponder. Also, a transponder replies to any reader (authenticated or illegitimate) that initiated the magnetic power burst. The RFID system can also easily fail under various security attacks in the forms of injection, eavesdropping, and denial of service.

Some RFID systems were designed with security in mind, employing a challenge-response protocol that enables the tag to respond to authentic readers only.[14] The disadvantages of such a system are bigger size (and it is currently impossible to be used in a patient's wristband) and a substantial cost increase (which becomes an implementation concern if each admitted patient in the hospital would be provided with a RFID-embedded wristband). Less expensive and smaller RFID transponders with built-in security functions do exist on the market, but as one research document by John Hopkins University[15] pointed out, it can easily be broken.

The implementation uses the Texas Instruments Series 2000 Low Frequency RFID reader (with no built-in security). The .NET TIS2000 SDK (Software Development Kit) is used to interface the Pocket PC application and the reader; the SDK provides a driver for the TIS2000 reader, which is padded with layers of security, reliability, and availability. The SDK documentation[16] mentions that RFID security issues cannot be addressed only by means of software. It provides a thin security layer that does not protect the Pocket PC application from the attacks mentioned previously. The document suggest enhancing the system with a separate source of security (not directly connected to the RFID submodule); the purpose of this change is to make the application "secure enough" within its context because a foolproof security solution is not possible.[16]

We define the proposed solution "secure enough" when the patient is correctly identified by a nurse or physician. Upon reading the patient's RFID tag, the Pocket PC application downloads the patient's profile along with his/her photo, a Moving Picture Experts Group (MPEG) file, displayed on the screen. The nurse or physician can make an on-site visual check that the RFID tag corresponding to the patient being identified is correct. Thus, even if the RFID tag of the patient has been maliciously cloned or injected, the nurse or physician can correctly identify the patient by making this a "secure enough" solution for security concerns.

Results and Discussion

Figures 3 and *4* show the simulation testing results of typical patient bedside flow activities conducted in a hospital in an experimental simulation environment using the WISH system with the actual RFID tag reading data compared to the current (traditional) bedside flow activities without using the WISH system. The studies were reviewed and performed at Palo Alto Medical Foundation and San Jose State University. The activities and the time typically expended in performing them made up the major portion of the control group. There were two doctors and four nurses involved in the overall simulation study.

There were five major physician's activities measured and their corresponding improvement in throughput: a) regular patient visit (27%), b) patient's status checkup (50%), c) patient's medication prescription (50%), d) scheduling patient activities (35%), and e) providing patient report (67%). The testing data show the following throughput improvement in nurse's activity: a) collecting patient vital sign data (40%), b) managing patient data (80%), c) scheduling patient activities (41%), d) patient's medication distribution (60%), e) patient's surgery procedure preparation (30%), and f) providing patient report (87%).

The summarized testing data show an average of 45.8% overall throughput improvement among the physician's activities per patient, and an average of 56.3% overall throughput improvement in the nurse's activities per patient. In addition, patients can gain more rest time from the activities.

In a study provided by the Kaiser Family Foundation in 2004, it indicates that a high percentage of patients rated the following items as "very important" causes of medical errors: "Overwork of health professionals," "Doctors not having enough time," "Not enough nurses in hospitals," "Poor handwriting by health professionals," and "Lack of computerized medical records."[7] All these medical error causes are related to the design objectives of the WISH system.

A detailed description of some selected nurse and physician activities with procedural steps used in the system's experimental simulation testing is shown in the Appendix. For each major physician and nurse activity listed above, a procedural description with similar types of experimental testing data using the WISH system was recorded and compared to the data using the traditional clinic procedure. The procedural steps and empirical data applied in the experimental simulations for each listed physician's and nurse's activity were reviewed with experienced professional physicians and nurses at a reputable medical facility.

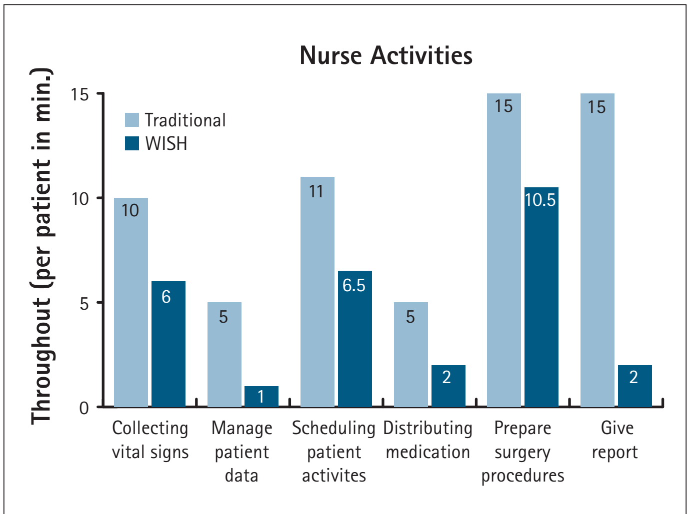

Fig. 3. Throughput (per patient) in nurse activities. WISH, Wireless Mobile Information Systems for Healthcare.

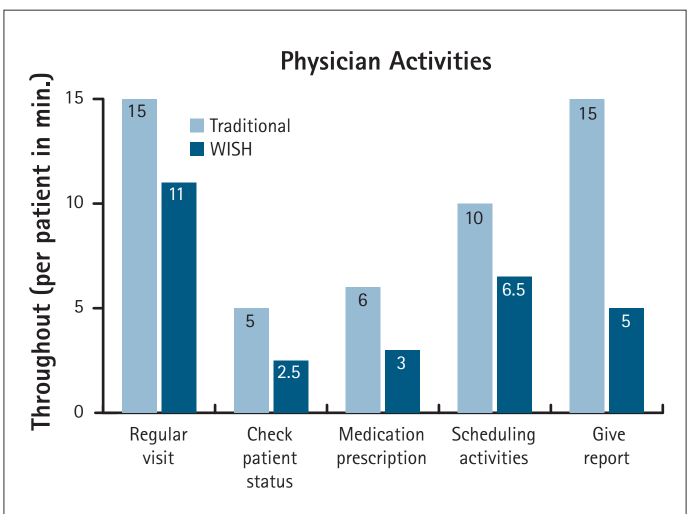

Fig. 4. Throughput (per patient) in physician activities. WISH, Wireless Mobile Information Systems for Healthcare.

Conclusions

Some of the routine tasks involved in each activity, such as patient identification, patient data access and update, and hospital resource availability check, can be automated and conducted almost anywhere and anytime in the hospital. The time involved in performing these tasks is significantly reduced. Other benefits of using the WISH system include the reduction of errors. The chance to identify an incorrect person or a patient file is very low.

As an example, consider the time it takes a nurse to correctly identify a patient and view the patient's profile on the screen; this is the time it takes for the RFID tag to be read and added to the turnaround time of the patient's profile (associated with that RFID tag) requested by the smart device from the local database or the central server. The testing shows that this patient identification and profile retrieval time is exceptionally small; the average time of reading an RFID tag is about 135.8 milliseconds and the average time of the device's profile request is about 0.5 seconds.

Wireless mobile technology is becoming more efficient and robust. These devices are capable of performing a variety of tasks in the healthcare field. Using real-time, interactive wireless mobile devices with RFID technology and multimedia features can bring a paradigm shift in healthcare from the traditional hospital model. The key factors to the success of such a paradigm shift include users' acceptance (physician, nurse, administrative staff, patient, etc.) and improved reliability and security features provided by the systems.[12] There are major advantages and business benefits in this approach.

The results of the study clearly show a significant improvement in throughput for the daily patient bedside workflow activities for hospital staff. The study shows that wireless Wi-Fi technology and RFID technology can help in reducing the effort required to compute time-consuming, routine tasks performed by nurses and physicians. We also highlight that the WISH system facilitates automatic tasks and procedures in a hospital, and it also helps to reduce the (high) number of problems caused by human error and manual processing.

It is important to point out that wireless and RFID technology alone can only improve patient bedside flow activities to a certain degree. In order to have a greater extent of benefits as we have discussed in the paper, a solid software design and implementation of a service-based architecture can provide a healthcare system with reliability, availability, maintainability, and security (which are the design objectives of the WISH system). The security topic was analyzed within each wireless technology domain.[12] The WiFi network employs the WPA standard as its encryption standard, and the patient identification module uses a combination of RFID and patient photo to provide a "secure enough" level of security. Indeed, the RFID system by itself could not provide a full level of security, because the hardware technology currently available does not provide it.

However, there is a need for more research on the suitability of different e-Health applications based on the level of available network Quality of Service.[17]

There are now a few ongoing international initiatives on mobile e-health[18] (also see www. mohca.org). Preliminary results indicate that the success of these initiatives would depend very much on the major stakeholders, namely the healthcare service providers including patients, physicians, surgeons, nurses, radiologists, pathologists and other medical professionals. Hence, we need to evaluate mobile multimedia technologies for healthcare using methodologies involving various stakeholders.[19]

Acknowledgment

The authors would like to thank previous San Jose State University (SJSU) graduate students Laurent Couraud, Timothee Bensimon, and Valentin Baudot for their earlier version of the project WISH, and the former SJSU undergraduate student Vincent Ngan for his testing work on the system (all supervised by W.D. Yu).

REFERENCES

1. Borriello G, RFID: Tagging the world, *Communications ACM* **2005**;34–37.
2. Yu WD, Ray P, Motoc T. A RFID technology based wireless mobile multimedia system in healthcare. In Proceedings of The 8th International Conference on e-Health, Networking, applications, and Services, August 17–19, **2006**, New Delhi, India, pp. 1–12.
3. Schmidt J, Healthcare's paper trail is costly route. *USA Today*, **2005**. http://www.usatoday.com (Last accessed July 4, 2007).
4. Goedert J, Early tales from the RFID front. *Health Data Management*, August **2004**. http://www.healthdatamanagement.com (Last accessed July 4, 2007).
5. Briggs B, Mobile technology comes from behind. Health Data Management, September **2004**. http://www.healthdatamanagement.com (Last accessed July 4, 2007).
6. US Department of Health & Human Services, Decade of Health Information Technology, US Secretarial Summit on Health Information Technology, Washington, July **2004**. http://www.hhs.gov (Last accessed July 4, 2007).
7. Kaiser Family Foundation, the Agency of Healthcare Research and Quality, and Harvard School of Public Health. National Survey on Consumers' Experiences With Patient Safety and Quality Information, **2004**.
8. Schuerenberg BK. Hospital dashes to wireless services. Health Data Management, September **2004**. http://www.healthdatamanagement.com (Last accessed July 4, 2007).
9. Gee CY, MobiHealth integrates RFID technology with wireless clinical solutions, PRWeb, May 3, **2004**. http://www.prweb.com (Last accessed July 4, 2007).
10. Schuerenberg BK, Memoirs of Wi-Fi networks. Health Data Management, September **2004**. http://www.healthdatamanagement.com (Last accessed July 4, 2007).
11. Per T, Ballagas R, Want R, Spontaneous marriages of mobile devices and interactive spaces. *Communications ACM* **2005**;45:53–59.
12. Wireless & Mobile Computing Security. http://www.mobileinfo.com/Security/index.htm (Last accessed July 4, 2007).
13. Boulter M. Smart client architecture and design guide. Microsoft patterns & practices. http://download.microsoft.com/download/9/a/1/9a1115fd-8ba8-4aa0-a82e-07044bd12ac0/SCAG.pdf (Last accessed July 4, 2007).
14. Iacobobici Y, Yu WD, Motoc T. RFID Security, San Jose State University, Computer Engineering Department, December **2005**.
15. Bono S, Green M, Stubblefield A, Rubin A, Juels A, Szydlo M. Analysis of the Texas Instruments DST. http://www.rfidanalysis.org (Last accessed July 4, 2007).
16. Motoc T. .NET RFID Software Development Kit for the Texas Instrument Series 2000 low frequency reader. San Jose State University, Computer Engineering Department, February **2006**.
17. Tulu B, Chatterjee S, A taxonomy of telemedicine efforts with respect to applications, infrastructure, delivery tools, type of setting and purpose. Proceedings of the 38th Hawaii International Conference on System Sciences, **2005**.
18. [ITU-D04], ITU-D, Mobile e-health services for developing countries, ITU-D study group 2 Document 2/202-E, August 10, **2004**.
19. Australia NewZealand Telehealth Committee. A methodology for telehealth evaluation in Australia. May **2000**.

Address reprint requests to:
Weider D. Yu, Ph.D.
Computer Engineering Department
College of Engineering
San Jose State University
One Washington Square
San Jose (Silicon Valley), CA 95192-018

E-mail: weider.yu@sjsu.edu

Received: July 4, 2007
Accepted: November 3, 2007

APPENDIX

COLLECTING VITAL SIGNS (NURSE)	TRADITIONAL TIME USED (MIN)	AUTOMATED BY WISH?	ACTIVITY STEP	TIME USED (MIN)
Walk to patient data repository	0.5	Yes	Auto	0
Search for patient's file	0.5	Yes	Auto	0
Check out patient's file	0.25	Yes	Auto	0
Walk to patient's room	1	No	na	1
Identify patient	0.5	Yes	DB & RFID	0.01
Collect vital signs				
Temperature measurement	1	No	na	1
Pulse measurement	1	No	na	1
Assessing respiration	1	No	na	1
Blood pressure measurement	1	No	na	1
Measuring oxygen saturation	1	No	na	1
Update patient file	1	Yes	DB	0.008
Walk back to patient data repository	0.5	Yes	Auto	0
Check in patient's file	0.25	Yes	Auto	0
Organize patient's file	0.5	Yes	Auto	0
Total	**10**			**6.018**
REGULAR VISIT (PHYSICIAN)	**TRADITIONAL TIME USED (MIN)**	**AUTOMATED BY WISH?**	**ACTIVITY STEP**	**TIME USED (MIN)**
Walk to patient data repository	0.5	Yes	Auto	0
Search for patient's file	0.5	Yes	Auto	0
Check out patient's file	0.25	Yes	Auto	0
Walk to patient's room	1	No	na	1
Identify patient	0.5	Yes	DB & RFID	0.01
Provide general care to patient	8	Yes	App	7.5
Update patient file	3	Yes	App & DB	2.5
Walk back to patient data repository	0.5	Yes	Auto	0
Check in patient's file	0.25	Yes	Auto	0
Organize patient's file	0.5	Yes	Auto	0
Total	**15**			**11.01**

App, use the applications in the Wireless Mobile Information Systems for Healthcare (WISH) system; RFID, read Radio Frequency Identification (RFID) tag; DB, access database information; na, do not apply.