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A Wireless ECG Monitoring System for Healthcare

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ABSTRACT

With aging of population, there has been a significant increase in the number of patients suffering from cardiovascular diseases. This results in an increased cost of healthcare associated with hospitalization, treatment and monitoring. In this paper, an architectural framework of a system that utilizes mobile technologies to enable continuous, wireless, electrocardiogram (ECG) monitoring of patients anytime anywhere is presented. The intelligent agents residing in the system detect any anomalous ECG readings and trigger an alarm that would be sent to the healthcare center in case of an emergency. The proposed system would not only provide a better quality of life to the patients by giving them the independence to move around freely in addition to continuous monitoring of heart but will also save healthcare costs associated with prolonged hospitalization of cardiac patients.

Keywords

Healthcare, E-health, Telemedicine, Wireless, ECG, Cardiology, Patient Monitoring.

INTRODUCTION

Cardiovascular disease is one of the main causes of death in the many countries including U.S. (Gouaux et.al; 2003), and in 1999, it accounted for over 15 million (about 30% of all) deaths worldwide. In addition, several million people are disabled by cardiovascular disease (WHO, 1999). The delay between the first symptom of any cardiac ailment and the call for medical assistance has a large variation among different patients (Gouaux et.al; 2003) and can have fatal consequences. One critical inference drawn from epidemiological data is that deployment of resources for early detection and treatment of heart disease has a higher potential of reducing fatality associated with cardiac disease than improved care after hospitalization. Hence new strategies are needed in order to reduce time before treatment. Monitoring of patients is one possible solution. Also, the trend towards an independent lifestyle has also increased the demand for personalized non-hospital based care (Tablado et.al, 2003).

A key factor related to cardiovascular disease is the presence of acute chest pain, however it can also be caused by other medical problems and then there are cases of cardiac arrests that are silent. The only reliable diagnostic tool available for assessing the probability of a cardiac event is ECG. It represents the electrical activity of the heart as recorded from electrodes attached to the body of a patient and is the most frequently performed test to evaluate the level of health of patients with malfunctioning or irregular functioning of the heart (Nussbaum et. al 2002, Schlant et. al, 1992, Liszka, et. al, 2004). The sensitivity and specificity of using ECG as a diagnostic tool can be greatly increased if a previous reference ECG of the patient is also available. This would eliminate the error caused by inter-patient variability and could allow for analysis of serial changes in ECG recordings (Gouaux et.al; 2003). Transmitting ECG signals to the hospital in case of an emergency situation has the potential of reducing response time in infarct control or resuscitation of sudden-cardiac deaths victims (Nussbaum et. al 2002).

With advances in wireless and mobile networks, ECG signals of patients can be transmitted to healthcare providers. This has been termed as wireless ECG monitoring and many challenges and possible solutions are shown in Table 1. The current research proposes a wireless ECG monitoring system, which not only provides monitoring of cardiac patients via a wireless monitor and a PDA but will also trigger an alarm at the healthcare center in case of a patient-specific or general anomalous event.

Challenges	Comments	Proposed Solution
Early detection of cardiac events in existing as well as potential patients	It will result in a treatment without delay and hence a reduction in the number of cardiac-related deaths.	Ubiquitous monitoring of people at risk of cardiac diseases will prevent the number of cardiac events that go unnoticed or fail to reach medical attention
Reduction in healthcare costs while providing improved patient care and healthcare quality	An increase in the size of the population with cardiac ailments, thereby, increasing healthcare costs associated with prolonged hospitalization	Promoting continuous, remote monitoring of patients with cardiac ailments, thereby, reducing hospitalization frequency and duration while providing improved quality of healthcare.
Improved quality of life for cardiac patients by increased mobility and independence in addition to timely medical attention	Increased hospitalization not only increases costs but also reduces mobility and independence of patients	Use the mobile technologies to provide a better healthcare to cardiac patients by an increased mobility and independence and quick medical assistance by sending alarms to the healthcare center for anomalous events.

Table 1. Challenges associated with Cardiac related deaths and Proposed Solution

The objective of the current research is to address the challenge of providing quality care to cardiac patients anytime, anywhere along with reducing healthcare costs by leveraging the benefits of mobile technologies to enable continuous, wireless ECG monitoring of patients. Ubiquitous monitoring of heart for signs of cardiac events which would have otherwise gone unnoticed would not only promote early detection and treatment of cardiac disease, hence reducing the fatality rate due to cardiac arrests, but would also reduce un-necessary hospitalization by promoting remote monitoring of patients requiring long term hospital stays thereby reducing healthcare costs (Varshney, 2004). The main contribution of the current research is to provide the architectural framework of a wireless ECG monitoring system that would utilize the capabilities of advanced mobile technologies to facilitate ubiquitous monitoring of ECG in order to detect the presence of an anomalous cardiac event.

Related Work in Wireless ECG

Work on related issues in ECG monitoring include "smart health wearable" research (Lymberis, 2003), interference for telemetry devices (Gieras, 2003), PDA as a mobile gateway (Jovanov, et. al., 2002), long-term health monitoring by wearable devices (Suzuki and Doi, 2001), a short range Bluetooth-based system for digitized ECGs (Mendoza and Tran, 2002), a wearable stethoscope (Kyu and Asada, 2002), and, real-time monitoring of patients in the home environment (Khoor, et. al, 2001). Clothing-embedded transducers for ECG, heart rate variability, and acoustical data and wireless transmission to a central server are proposed in (Jovanov, et. al. 2002). A requirement model for delivering alert messages is presented in (Kafeza, et. al, 2004). A design approach for ECG data compression for a mobile tele-cardiology model is presented. Authors achieved a significant compression ratio and reduction in transmission time over GSM network (Istepanian and Petrosian, 2000). Personal health monitors based on a wireless body area network (BAN) of intelligent sensors are proposed for stress monitoring (Jovanov, et. al, 2003). There are many portable monitors that are available today such as Micropaq that allows multi-parametric information to be transmitted over wireless LANs (Welch Allyn, 2005) and LifeSync (WirelessECG, 2005), which uses bluetooth to move information within a hospital infrastructure.

There has been some work in ECG monitoring of patients using wireless networks (Liszka, et. al, 2004). It presents a prototype of system where a portable ECG monitor is used along with wireless networks to monitor arrhythmias. The system uses a fixed sampling rate of 250 and transmits a 9-byte minimum message for every measurement in 4 milliseconds. Although the paper presents many system-level issues and makes significant contributions, it suffers from many problems: (a) it requires considerable bandwidth per person and will affect scalability once the number of patients increase significantly, (b) it is tied to using GPS for location tracking and will have limited usability in indoor environments and places where direct line of sight is not possible, (c) it is dependent on certain type of wireless networks (bluetooth and GPRS). The proposed system will include scalable operation as information will be transmitted only when needed and even then a prioritized transmission can be used to improve network delays. Also, the proposed system allows multiple technologies for location management and thus is more usable and also is not tied to certain type of wireless networks. The proposed system can be implemented on WLANs, bluetooth, and ad hoc wireless networks in addition to backboned by satellites, wide area wireless networks, and cellular/PCS/GSM type wireless networks. Additionally, the current research proposes the use of intelligent

agents as a means of analyzing and diagnosing ECG data thereby reducing the cognitive over load of healthcare professionals and increasing efficiency. The proposed work includes an architectural framework to promote continuous wireless monitoring of ECG utilizing the capabilities of intelligent agents, PDAs, and mobile networks, protocols for the wireless ECG monitoring system, identification of various technical as well as non-technical challenges and solutions associated with wireless monitoring of cardiac patients, and identification of direction for future research in the area of m-health. Our work has the potential of being implemented in a healthcare setting and will also be validated using real-world data in the near future.

ARCHITECTURAL FRAMEWORK FOR WIRELESS ECG MONITORING SYSTEM

In this section, we present an architectural framework of the proposed system (Figure 1), which consists of the following components:

- An easy to wear mobile ECG monitoring device, which provides 1 ECG record lead and consists of two electrodes that are attached to the patient's body.

- A Personal Digital Assistant (PDA) for the patient with intelligent agents to acquire the ECG data from the monitor, perform the analysis of the recorded ECG readings and send alarm messages to the healthcare center in case an anomaly is detected.

- A PDA for the doctor and the health care center whose primary goal is to provide quick medical assistance to the cardiac patient anywhere and anytime when an anomalous condition is detected.

- The communication/information exchange between the intelligent agents in the patient's PDA, the health care center and the doctor's PDA takes place via a wireless communication network. Hence the patient is continuously monitored for changes in cardiac events regardless of the location within the coverage of the network.

The field of medicine is inherently mobile, and doctors and other healthcare professionals needing fast and easy access to critical data from a remote location are adopting mobile technologies at a fast rate (Editorial-Postgraduate Medicine Online, 2004). Furthermore, the use of PDA as a component of the proposed system stems from the many advantages such as ease of use, very little training and ubiquitous access to data. In Canada alone, there are over 1,000,000 PDA users who require no personal training or support towards learning to use PDAs (Goldberg and Wickramasinghe, 2003). Some of the prior researches in telemedicine have merely used PDAs as a tool to capture and send data to a remote location instead of leveraging the power of PDAs to carry out computational analysis that can save costs, lower the burden on network traffic and detect anomalies earlier (Tablado et.al, 2003). The advances in wireless technologies have made it possible to record and transmit digital ECG signals using a patient device from a remote location to the computer or hand-held PDA of a health care professional instantly, hence reducing the time taken for evaluation and treatment (Gouaux et.al, 2003, Nussbaum, et. al, 2002, Khoor, et. al, 2001, Hung, et al. 2003). Most of these systems record ECG readings and continuously send them to the healthcare center for further study and analysis.

The objective of the current research is to monitor patients for any changes in cardiac events and provide them with quick medical assistance when needed while at the same time reduce network traffic and healthcare costs. Therefore, the proposed system doesn't transmit a continuous stream of ECG signals to the healthcare center, thereby reducing network traffic and the cognitive load on the healthcare professional. Instead, the proposed system for wireless ECG monitoring analyzes serial ECG recordings and detects the presence of an anomalous condition by the use of intelligent agents located in the patient's PDA. The intelligent agents use an ontology that categorizes different alerts, which correspond to violations of boundary conditions as specified by the threshold ECG recordings. The ontology is represented using DAML+OIL (DAML, 2000), which is based on Description Logics (DL, 2003). These agents carry out a large chunk of analysis of the ECG in the PDA and send alerts only if an anomaly is detected thereby reducing traffic on the wireless networks, making the system more cost-efficient and involving the health care structure without delay *but* only when needed.

An Intelligent Agent is a software entity that has reasoning, planning and learning capability along with the capability to communicate with other agents in order to accomplish a certain goal specified by the user. It shows autonomous behavior and can react in a timely manner in response to certain pre-defined anomalous conditions (Nealon, et al., 2003). It is a mammoth task for a healthcare professional to interpret, analyze and provide error free diagnostics based on vital data stream, such as ECG readings, collected from a patient who is continuously monitored to detect anomalous conditions (Susan, et al, 2002). The use of intelligent agents with clear goals and relevant knowledge, as proposed in the current research, has the capability of assisting healthcare professionals in continuous patient monitoring in the form of ongoing analysis and diagnosis of large amount of complex data and alerting the health center in case of an anomaly via multi agent communication. This has the

benefit of not only reducing the cognitive overload of health care professionals but also promoting timely intervention of health care structure as and when required. Some of the other systems that have used intelligent agents in healthcare domain are described by (Moreno et al., 2002, Mouratidis et al., 2002, Susan, et al., 2002 and Tablado et al. 2003). But except for Tablado et al. (2003) none of these systems have proposed the usage of intelligent agents in conjunction with the PDAs, as is proposed in the current research. The use of intelligent agents in healthcare is still in its infancy but the future hold tremendous promises of deploying intelligent agents in a large scale to mobile users. Some of the major telecommunication companies such as Motorola, Fujitsu and BT are taking great initiatives in providing accessibility to agent based services via mobile devices such as mobile phones, PDAs or portable PCs (Moreno et al. 2002).
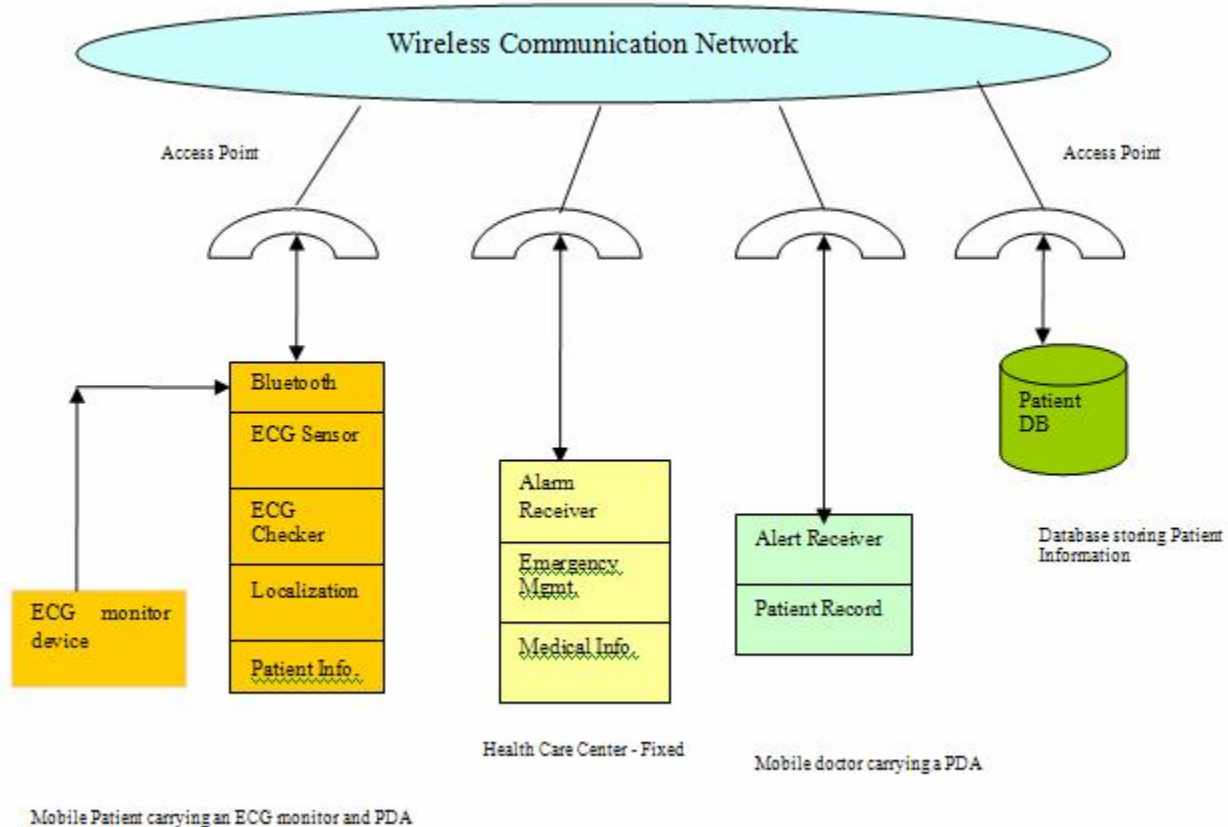

Figure 1: Framework of the Wireless ECG Monitoring System with Intelligent Agents

Configuration of the Patient's PDA

Before the patient will start using the monitoring system, the ECG Checker Agent located in the patient's PDA will be configured by a physician based on the current/past conditions of the patient, thus providing individual patient-centered care. The physician specifies the thresholds, which the ECG Checker Agent will refer to before triggering a low, medium or high-level alarm. The time interval between two ECG readings under normal conditions (Record ECG every 10 seconds) as well as abnormal conditions, i.e., after detection of an anomalous reading, (Record ECG every 1 second for the next 1 minute) is also configured. Four different measures of ECG; ECG1, ECG2, ECG3, ECG4 are stored and used as references. The ontology that categorizes the different alerts is based on the following logical statements:

- Normal Condition – Recorded ECG is between ECG2 and ECG3.
- Abnormal Conditions (Alert Range)
     1. Low Level Alarm – Recorded ECG is equal to ECG2 or ECG3 (ECG Recording is at the boundary level)
     2. Medium Level Alarm – Recorded ECG is between ECG3 and ECG4   (Above normal).

Recorded ECG is between ECG2 and ECG1   (Below normal).

3. High Level Alarm – Recorded ECG is above ECG4 or below ECG1 (Emergency level)

The ontology is built in each PDA by a specialist that describes the alerts that must be checked for every patient. Once the ECG Checker Agent is configured it subscribes to the ECG Sensor Agent and informs the ECG Sensor Agent of the ECG thresholds (ECG2 AND ECG3) that it is interested in and the time interval between two ECG readings under normal conditions. Once the ECG Sensor Agent receives the message it sends an agree message back to the ECG Checker Agent acknowledging the acceptance of the subscription.

DESCRIPTION AND PROTOCOL FOR WIRELESS ECG MONITORING SYSTEM

Table 2 below gives a detailed description of the functionality and protocol of each component in the Wireless ECG Monitoring System.

Component Name	Objective/ Functionality	Protocol
ECG Monitor	To measure the ECG of the patients. The portable ECG is carried by the patient 24 hrs a day. The ECG device has two electrodes that are attached to the patient and provide a single channel ECG Signal (Nussbaum et. al, 2002)	
PDA Of The Cardiac Patient		
Bluetooth Agent	The Bluetooth agent resides in the PDA and uses wireless communication to retrieve ECG readings from the wireless ECG monitor (Tablado et.al, 2003).	
ECG Sensor Agent	The ECG Sensor receives ECG data via Bluetooth, checks the ECG data for any anomalous conditions and if an anomalous condition is detected then it sends the message to ECG Checker regarding the presence of the anomalous situation.	IF ECG[E] < = ECG2 GENERATE MESG TO THE ECG CHECKER WITH THE CURRENT ECG[E] ELSE IF ECG[E] > = ECG3 GENERATE MESG TO THE ECG CHECKER WITH THE CURRENT ECG[E] ELSE CONTINUE NORMAL ECG RECORDINGS
ECG Checker Agent	The ECG Checker analyses the ECG data received from ECG Sensor and requests an intensive monitoring. The ECG data received for the one minute is analyzed based on the alert conditions defined in the ontology and accordingly a low, medium or high-level alarm is triggered if required. The alarm triggered is sent to the Alarm Receiver at the Health Care Center along with a report including the patient's ID, Name, DOB, Blood Group, Current location, and the ECG readings over the past one minute and prescription drugs. The data is transmitted via Wireless Communication Network.	IF ECG[E] < = ECG2 OR IF ECG[E] >= ECG3 REQUEST ECG SENSOR TO RECORD ECG AT 1 SEC. INTERVAL FOR THE NEXT 1 MIN. IF FOR THE NEXT 1 MIN. ALL ECG[E] = ECG2 OR ECG[E] = ECG3 SEND A LOW LEVEL ALARM TO THE ALARM RECEIVER AT THE HC // ECG reading on the lower or upper normal boundary conditions ELSE IF FOR THE NEXT 1 MIN. ALL ECG[E] < ECG2 AND ECG[E] > ECG1 SEND A MEDIUM LEVEL ALARM TO

Component Name	Objective/ Functionality	Protocol
		THE ALARM RECEIVER AT THE HC
		ELSE IF FOR THE NEXT 1 MIN. ALL ECG[E] > ECG3 AND ECG[E] < ECG4
		SEND A MEDIUM LEVEL ALARM TO THE ALARM RECEIVER AT THE HC
		// ECG reading below or above normal
		ELSE IF FOR THE NEXT 1 MIN. ALL ECG[E] < ECG1 OR ECG[E] > ECG4
		SEND A HIGH LEVEL ALARM TO THE ALARM RECEIVER AT THE HC
		// ECG readings in the emergency level
		ELSE ECG CHECKER RETURNS TO NORMAL STATE, SENDS MESG. TO THE ECG SENSOR TO RETURN TO NORMAL INTERVAL FOR CHECKING ECG.
		// Not all ECG readings recorded were in the alert zone.
		ALARM MESSAGE
		ALRM MSG [PATIENT'S ID, NAME, ADDRESS, DOB, MEDICAL CONTACTS INFORMATION, PRESCRIPTION DRUGS, BLOOD GROUP, CURRENT LOCATION, ECG READINGS OVER THE PAST 1 MIN., LEVEL OF ALRAM]
		// The message and data will be encoded in XML. ECG readings will be encoded in SCP-ECG format (CEN/TC251, 2003) and bundled together in the message encoded in XML
Localization Agent	Localization agent uses GPS and/or other location tracking systems (WLANs, RFID etc) to determine the present location of the patient.	
Patient Info. Agent	Stores information about the patient such as: ID, name, address, date of Birth (DOB), medical contacts information, scheduling information, blood group, prescription drugs	
Health Care Center – ECG data is transmitted from the PDA to the Health Care Center via GPRS regardless of the location of the patient within the coverage of the network (Nussbaum et. al, 2002)		
Alarm Receiver Agent	Receives alarm sent by the PDA of the patients along with the report. Sends the report received to Emergency Mgmt. And Medical Info. Agents. Sends acknowledgement to the ECG Checker Agent confirming that the alert has been received and is being managed.	RECEIVE ALRM MSG SEND THE ALRM MSG TO EMERGENCY MGMT AND MEDICAL INFO. SEND ACKNOWLEDGEMNT BACK TO ECG CHECKER AT PATIENT'S PDA

Component Name	Objective/ Functionality	Protocol

Emergency Mgmt. Agent	In case of *low level alarm*, the patient is contacted and is scheduled for a visit. A message is sent to the patient's PDA for scheduling a visit to see the doctor. This will cause a message to flash on the PDA and sound a low-level beep so that the patient would take notice and contact the doctor.
	
	In case of a *medium level alarm*, a message is sent to the PDA of the doctor on call. The message consists of the level of alarm and the patient's report received from the Alarm Receiver Agent. The doctor analyses the ECG report, contacts the patient with the result of the analysis and schedules an appointment ASAP. If the doctor sees the need then the emergency unit is dispatched.
	
	In case of a *high level alarm*, the emergency unit is contacted with the patient's location, ID and the ECG reading. A message is then sent to the PDA of the doctor on call. The message consists of the level of alarm and the patient's report received from the Alarm Receiver Agent. The specialist analyses the ECG report and keeps the emergency unit abreast with the result via wireless communication
		IF ALARM LEVEL = LOW
		
		    MESSAGE SENT TO INFORMATION AGENT ON PATIENT'S PDA TO SCHEDULE A VISIT WITH THE DOCTOR
		ELSE IF ALARM LEVEL = MEDIUM
		    SEND ALARM MESSAGE TO THE PDA OF DOCTOR
		// doctor then analyses the alarm message and takes requisite actions
		ELSE IF ALARM LEVEL = HIGH
		    SEND ALARM MESSAGE TO THE EMERGENCY UNIT REQUESTING THE UNIT TO BE DISPATCHED TO THE PATIENT'S LOCATION IMMEDIATELY
		 SEND ALARM MESSAGE TO THE PDA OF DOCTOR

Medical Info. Agent	Update the patient's EMR (electronic medical record) with the ECG report received from Alarm Receiver. The update includes the ECG report, the level of alarm triggered and the date of the event	LOCATE PATIENT'S EMR IN THE CENTRAL DATABASE USING PATIENT'S ID AS KEY UPDATE PATEINT'S EMR WITH THE INFORMATION PROVIDED IN THE ALRAM MESSAGE, DATE OF THE ALARM EVENT.
PDA of the Doctor		
Alert Receiver Agent	Receives alarms from Emergency Mgmt. Agent and sends a confirmation to the Emergency Mgmt. Once the doctor has received the message and acknowledged the alarm by responding to it. Sounds a medium or high level beeps along with flashing the alarm message on the doctor's PDA so that the doctor takes notice of the alarm sent.	
Patient Record Agent	Queries the patient database on doctor's request and updates the database with information provided by the doctor	

Table 2. Components, Functionality and the Protocol Associated with Each Component in the Proposed System

USAGE SCENARIO OF WIRELESS ECG MONITORING SYSTEM

Let us consider the case of a cardiac patient who is 60 years old and needs continuous monitoring of heart to detect any changes in the cardiac events. The doctor has prescribed him to use the wireless ECG monitoring system. His PDA has been configured with the threshold ECG readings and the alerts have been categorized. On one beautiful day, he went out to play golf and on the golf course he had a cardiac arrest. Figure 2 below represents the usage scenario. At that moment, in the continuous monitoring cycle of the ECG Sensor Agent an ECG reading was recorded that detected an anomalous event. The ECG Checker Agent was informed of the situation, which requested the ECG Sensor Agent to continue monitoring the ECG recordings every second over the next one minute and to be informed of each recording. If any of the ECG readings recorded over the one minute time interval falls in the normal recording range (as defined by the ontology) then the ECG Checker Agent returns to the normal state and informs the ECG Sensor Agent to continue the normal recording and cancel the intensive recordings. But since all the ECG recordings fall in the abnormal range so an alarm is triggered and a message sent to the Alarm Receiver Agent of the Health Care Center. Suppose the alarm was a high level alarm. The Alarm Receiver Agent contacts the Emergency Mgmt. Agent and the Medical Info. Agent with the message received from the ECG Checker Agent at the PDA of the patient. Since the alarm is a high level alarm, an ambulance is immediately dispatched to the location of the patient while the doctor on call analyses the ECG report and guides the healthcare professionals on the way to the patient and tells them exactly what to do stabilize the patient. The ambulance reaches the victim in time and since the ECG report has already been analyzed, no time is lost and the victim is resuscitated. The patient's record is updated.
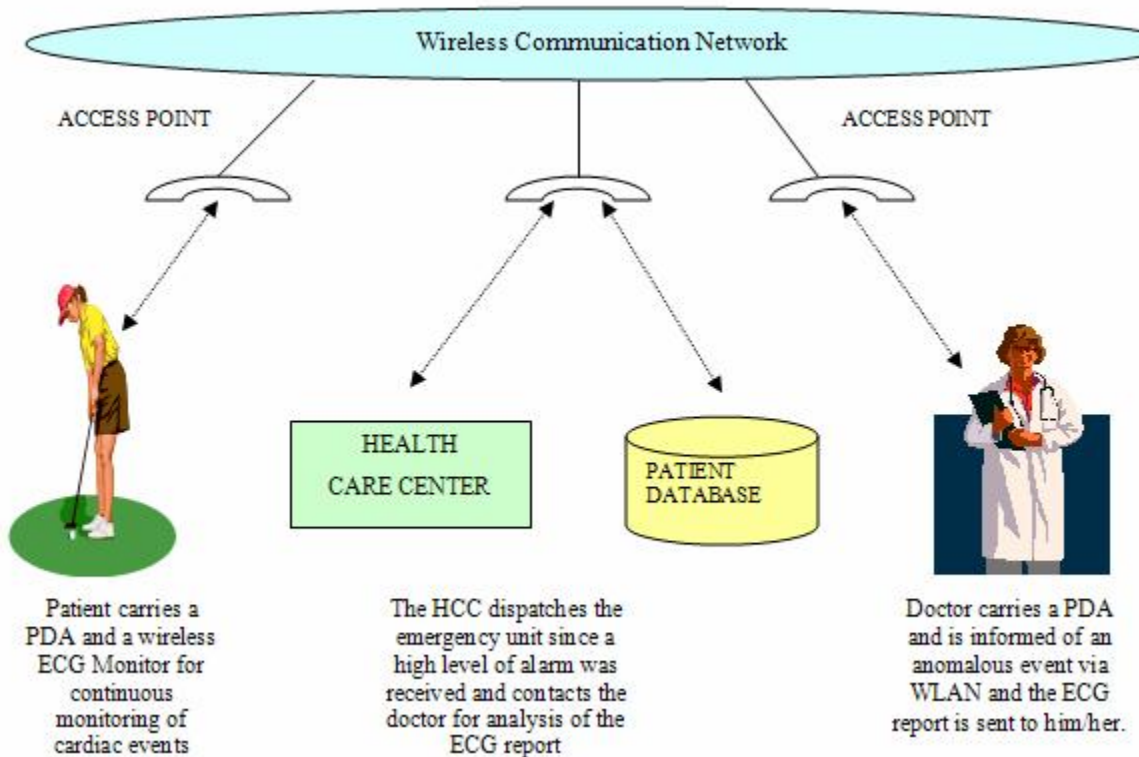

Figure 2. A Typical Scenario for the Usage of Wireless ECG Monitoring System

In the absence of the wireless ECG monitoring system, the cardiac arrest had the potential of claiming the life of the patient since there was no way to get help on a golf course where there was no one in close proximity to the patient. Even if there was someone around, it would have taken sometime for the person to realize what was happening and since the medical team had no way of knowing the current state of the victim a few extra minutes would have been lost in diagnosing the extent of the cardiac event. In a cardiac arrest, where the difference of a minute means the difference between life and death, the importance of ubiquitous monitoring of cardiac events in preventing fatalities and promoting well-being of cardiac patients is phenomenal.

Before the patient will start using the monitoring system, the ECG Checker Agent located in the patient's PDA will be configured by a physician based on the current/past conditions of the patient, thus providing individual patient-centered care.

Figure 3 below represents the logical flow of information between components/intelligent agents of the wireless ECG monitoring system and depicts the computation and analysis made by the intelligent agents housed in the patient's PDA, the healthcare center and the doctor's PDA.
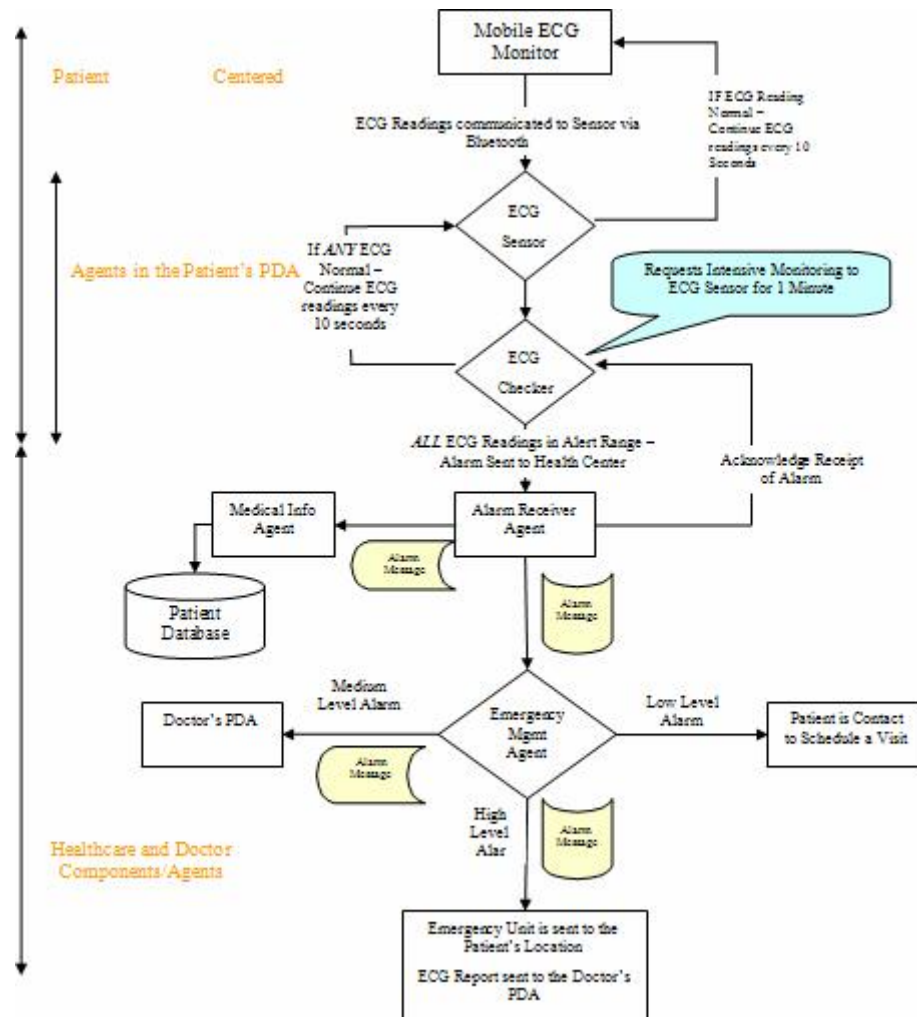

Figure 3. Information Flow between Components/Intelligent Agents of Wireless ECG Monitoring System

CURRENT ISSUES AND FUTURE RESEARCH

It is our hope that some of the current issues will open the door for future research. The current research proposes the use of mobile technologies to address the problem of rising healthcare costs in context to long-term hospitalizations, monitoring and treatment of cardiac patients in addition to early detection and reduction in cardiac-death victims. The use of wireless solutions has multiple advantages and it brings unique opportunities for patients, doctors and healthcare industry and can be leveraged to changing healthcare environment, but at the same time it brings challenges of its own (Kara, 2001).

In the light of HIPAA, security and reliability of transactions made over a wireless network are important concerns. Since critical patient information is transacted in the wireless solution, hence there is a need to provide secure healthcare transaction environment while providing high quality healthcare (Wickramasinghe et al., 2004). The use of Ad-hoc wireless network to augment the current wireless networks is a viable option to increase the reliability of patient monitoring (Varshney, 2004).

The proposed solution may result in some cost saving as healthcare resources can be utilized more efficiently, however several cost factors such as cost of medical equipment, PDA, location-monitoring by multiple technologies, and cost of

responding medical personnel must be included. Certainly cost-benefit analysis must compare the additional cost with the cost associated with long-term hospitalization.

The issue of usability of the system along with the level of trust of doctors and patients in the system should be studied in order to make the system pervasive. The aging population suffering from heart diseases and requiring prolonged hospitalization due to continuous monitoring of heart are willing to begin using wireless and mobile technologies as long as these technologies would truly provide independence along with ubiquitous monitoring (Varshney, 2003).

Furthermore, the success of m-health requires a giant paradigm shift in the way healthcare is delivered and practiced (Wickramasinghe et al., 2004). The adoption and success of wireless solution proposed depends on the willingness of the major stakeholders such as doctors, patients and healthcare providers to adopt the technology.

Another direction for future research in the field of cardiac diseases is the possibility of implanting electrodes in the body of patients at risk of cardiac diseases or current patients who require continuous monitoring. This will eliminate errors in ECG readings caused by misplaced electrodes or electrodes falling out of place.

CONCLUSION

Cardiovascular disease is one of the major causes of untimely deaths in U.S. ECG readings are by far the only viable diagnostic tool that could promote early detection of cardiac events. Wireless and mobile technologies are key components that would help enable patients suffering from chronic heart diseases to live in their own homes and lead their normal life, while, at the same time being monitored for any cardiac events. This will not only serve to reduce the burden on the dwindling resources of the healthcare center but would also improve the quality of healthcare by adding the *anywhere, anytime* paradigm to the healthcare sector. In this paper, we presented an architectural framework of a system that utilizes mobile technologies to enable continuous, wireless, electrocardiogram (ECG) monitoring of patients anytime anywhere. The intelligent agents residing in the system would detect any anomalous ECG readings and would trigger an alarm that would be sent to the healthcare center in case of an emergency. Hence the system would not only provide a better quality of life to the patients by giving them the independence to move around freely in addition to continuous monitoring of heart but will also save healthcare costs associated with prolonged hospitalization of cardiac patients.

ACKNOWLEDGMENTS

REFERENCES

1. DAML Website: http://www.daml.org (2005)

2. Description Logic Homepage: http://dl.kr.org (2003)

3. Gieras, I. A. (2003) The proliferation of patient-worn wireless telemetry technologies within the U.S. healthcare environment, *Proceedings of 4th International IEEE EMBS Special Topic Conference on Information Technology Applications in Biomedicine,* 295-298.

4. Goldberg, S. and Wickramasinghe, N. (2003) 21st Century Healthcare-The Wireless Panacea, *In Proceedings of the 36th Hawaii International Conference on System Sciences*

5. Gouaux, F., Simon-Chautemps L., Adami S., Arzi M., et.al; (2003) Smart Devices for the Early Detection and Interpretation of Cardiological Syndromes, *In Proc. 4th Annual IEEE Conf. On Information Technology Applications in Biomedicine, UK.*

6. Hung, K. and Zhang, Y. (2003). Implementation of a WAP-Based Telemedicine System for Patient Monitoring, *IEEE transactions on Information Technology in BioMedicine, Vol. 7 No. 2, June 2003*

7. Istepanian, R. S. H. and Petrosian, A. A. (2000) Optimal Zonal Wavelet-based ECG Data Compression for a Mobile Telecardiology System, *IEEE Transactions on Information Technology in Biomedicine*, 4, 3, pp. 200-211, Sept.

8. Jovanov. E., O'Donnel. A., Morgan. A., Priddy B., Hormigo. R., (2002) Prolonged telemetric monitoring of heart rate variability using wireless intelligent sensors and a mobile gateway, *In Proc. of the Second Joint IEEE EMBS/BMES Conference, 2002 (24th Annual EMBS Conference and the Annual Fall Meeting of the Biomedical Engineering Society),* 1875-1876.

9. Jovanov, E., O'Donnell Lords, A., Raskovic, D., Cox, P. G., Adhami, R. and Andrasik, F. (2003) Stress Monitoring using a Distributed Wireless Intelligent Sensor System, *IEEE Engineering in Medicine and Biology Magazine*, 22, 3, May-June, pp. 49-55

10. Kafeza, E., Chiu, D. K. W., Cheung, S. C. and Kafeza, M. (2004) Alerts in Mobile Healthcare Applications: Requirements and Pilot Study, *IEEE Transactions on Information Technologies in Biomedicine*, 8, 2, pp. 173-181.

11. Kara, A. (2001) Protecting Privacy in Remote-Patient Monitoring, *IEEE Computer*, 34, 5, 24-27.

12. Kern, S. E and Jaron, D. (2003) Healthcare Technology, Economics and Policy: An Evolving Balance, *IEEE Engineering in Medicine and Biology Magazine*, 22, 1, 16-19.

13. Khoor, S., Nieberl, K., Fugedi, K., Kail, E. (2001) Telemedicine ECG-telemetry with Bluetooth Technology, *In Proc. Computers in Cardiology 2001,* Rotterdam, 585-588.

14. Kyu J. C. and Asada, H. H. (2002) Wireless, Battery-less Stethoscope for Wearable Health Monitoring, *In Proc. the IEEE 28th Annual Northeast Bioengineering Conference,* Philadelphia, PA, 187-188.

15. LifeSync – www.wirelessecg.com, 2005

16. Liszka, K. J., Mackin, M. A., Lichter, M. J., York, D. W., Pillai, D., and Rosenbaum, D. S. (2004) Keeping a Beat on the Heart, *IEEE Pervasive Computing*, October-December, pp. 42-49.

17. Lymberis, A. (2003) Smart Wearables for Remote Health Monitoring, from Prevention to Rehabilitation: Current R&D, Future challenges, *Proceedings of 4th International IEEE EMBS Special Topic Conference on Information Technology Applications in Biomedicine,* 272 – 275.

18. Mabry, S. L., Kollmansberger, S. J., Etters, T. and Jones, K. (2002). IM-Agents for patient monitoring and diagnostics. *In 15th European Conference on Artificial Intelligence, 22 July 2002*

19. Medical Informatics – Standard Communication Protocol – Computer Assisted Electrocardiography, CEN/TC251, 2003

20. Medicine on the Move, Editorial, Postgraduate Medicine Online, McGraw Hill, Feb. 2004

21. Mendoza, G. G. and Tran, B. Q. (2002) In-home Wireless Monitoring of Physiological Data for Heart Failure Patients, *In Proc. of the Second Joint IEEE EMBS/BMES (24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society) Conference*, 1849-1850.

22. Moreno, A. and Isern, D. (2002). Offering agent-based medical services within the AgentCities project. *In 15th European Conference on Artificial Intelligence, 22 July 2002*

23. Mouratidis, H., Manson, G., Giorgini, P. and Philp, I. (2002). Modeling an agent-based integrated health and social care information system for older people. *In 15th European Conference on Artificial Intelligence, 22 July 2002*

24. Nealon, J. L., and Moreno, A. (2003) Agent Bases Health Care Systems, *In Applications of Software Agent Technology in the Health Care Domain, Birkhauser, Verlag, pp 3-18, 2003*

25. Nussbaum, D., Wu X. (2002) An architecture of Scalable Wireless Monitoring System, *In Proc. of the 25th Annual international Conference of the IEEE EMBS,* Cancun*, Mexico, September 2003*

26. Schlant R.C, Adolph R.J., DiMarco J.P. et al. (1992) Guidelines for Electrocardiography, A Report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures [Committee on Electrocardiography] 1992; 19:473-481.

27. Sinha, N., M.D. – Provided valuable input in the verification of the architecture of wireless ECG monitoring.

28. Suzuki, T. and Doi, M. (2001) LifeMinder: An Evidence-Based Wearable Healthcare Assistant, *Proceedings of the ACM CHI Conference*

29. Tablado, A., Illarramendi A., Bermudez J., Goni A. (2003) Intelligent Monitoring of Elderly People; *In Proc. 4th Annual IEEE Conf. On Information Technology Applications in Biomedicine, UK.*

30. Varshney, U. (2003) Pervasive Healthcare, *IEEE Computer*, 36, 12, 138-140, December

31. Varshney, U. (2004) Using Wireless Networks for Enhanced Monitoring of Patients, *Proceedings. Of the 10th Americas Conference on Information Systems; NY, NY August 2004*

32. Welch Allyn's Website for Micropaq (http://www.monitoring.welchallyn.com/products/wireless/micropaq.asp)

33. Wickramasinghe, N., Geisler, E., Fadlalla, A. and Schaffer, J. (2004). A framework for Assessing E-Health Preparedness, *Proceedings of the 10th Americas Conference on Information Systems; NY, NY August 2004*

34. World Health Organization, Death by cause, sex and mortality stratum in WHO Regions, 1999.