Around the Clock Personalized Heart Monitoring Using Smart Phones

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Abstract: This paper describes work in progress regarding personalized heart monitoring using smart phones. Our research combines ubiquitous computing with mobile health technology. We use wireless sensors and smart phones to monitor the wellbeing of high risk cardiac patients. The smart phone analyses in real-time the ECG data and determines whether the person needs external help. Depending on the situation the smart phone can automatically alert pre assigned caregivers or call the ambulance. It is also used to give advice (e.g. exercise more) or to reassure the patient based on the sensors and environmental data.

Keywords: heart monitoring, smart phones, wireless ECG sensors

Introduction

The estimated direct and indirect cost of cardiovascular diseases in the United States alone is $393.5 billion for 2005 according to [3]. Statistics indicate that approximately $4 billion of unnecessary medical costs are spent each year on the assessment of non-cardiac cases in hospital emergency departments.

To reduce these costs and the anxiety of people with known cardiovascular problems we propose a portable monitoring system that monitors the heart and notifies the person or external party in case of abnormalities. Our monitoring system is meant for patients that have a known cardiovascular disease and need to be monitored around the clock.

Traditional heart monitoring solutions exist for many years such as the Holter device which records the patient's ECG for 24 to 48 hours and is then analysed afterwards by the cardiologist. The patient can 'wear' the device and go home and resume his/her normal activities. The main drawback of these solutions is when a major incident occurs during the monitoring phase which is recorded but no immediate action is taken to help the user. Other solutions have been introduced that address this problem and J. Rodriguez et al have classified these solutions in two groups [22]:

The first group uses smart phones (or PDAs) equipped with biosensors that record the heart signals and transmit them to a health care center or hospital for analysis. Some solutions can store the signals locally as well. Examples include Alive technology [2], Vitaphone [25], Ventracor pocketview [24] or Welch Allyn Micropaq

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[26]. Most are capable of recording, viewing and storing ECGs directly on the smart phone. Some solutions transmit the stored ECG to the health care center using wireless technologies (e.g. GPRS).

The second group aims at building platforms for real-time remote health monitoring. Examples are Mobihealth[12], Telemedicare[23], Osiris-SE[16] and PhMon[18]. These solutions use (wearable) wireless sensors to monitor patient's vital signs (e.g. ECG, oximeter, blood pressure). The European project Myheart [14] develops such a platform and focuses on heart patients. Myheart aims at designing intelligent biomedical clothes for monitoring, diagnosing and treatment. The platform developed by this second group collects the bio data and send it to a care-center or a hospital for processing and analysis. None of these solutions process the ECG data locally on the smart phone, and the ECG signals need to be continuously transferred to a health center if the patient needs to be monitored 24/7. This can be costly when GPRS is used for transmitting the data.

To deal with this issue several research projects consider processing the ECG data on a local device. Example projects are Amon, Epimedic and Molec.

AMON [4] is a wrist-worn medical monitoring and alert system targeting high-risk cardiac and respiratory patients. The system includes continuous collection and evaluation of several vital signs, smart medical emergency detection, and is connected to a medical center. For heart monitoring, they are technically limited by the fact the device is worn on the wrist and therefore the ECG signal is very noisy and not suitable to diagnose cardiac abnormalities.

Epi-medics project [9] defines an intelligent ECG monitor which can record, analyse the ECG signals and other sensor information and can generate alarms. It can also be personalized but it is not a device meant to monitor the patient 24/7. The patient connects to the 12 lead monitor periodically as directed by the heart specialist or when he/she doesn't feel well.

MOLEC[22] provides a solution that analyses the ECG locally on a PDA. It generates alarms to the hospital in case of high risk arrhythmias.

Our objective is to investigate and develop an application whereby a heart patient is monitored using various types of sensors (ECG, accelerometer, Oxygen). The sensor information is collected and transferred wirelessly to a smart phone. Our solution analyses the ECG on the local device. One distinction of our solution compared to the others is that we can personalise the monitoring and we have mechanisms in place to locate the user in case of emergency whether the patient is indoors or outdoors. We detect life threatening arrhythmias and give the patient general information about their health when they are not in a dangerous situation. We can also store extra information for further use by the health providers.

This paper presents a 24/7 personalized heart monitoring system. Section 1 presents the overall architecture and section 2 focuses on the implementation of the ECG component. Finally, section 3 concludes this paper.

1. Architecture

Figure 1 shows an overview of our heart monitoring architecture. The heart patient has one or more sensors (e.g. ECG, accelerometer, Oxymeter) attached to his/her body. External devices are used, such as a blood pressure monitor or scale, to collect periodically additional health data. We use off-the-shelf technology enabling us to incorporate the best sensors as they appear on the market. The sensors we use are Bluetooth enabled or integrated into the smart phone (e.g. GPS). The smart phone processes the sensor data and monitors the patient's wellbeing, and in case of an emergency, it automatically calls an ambulance to the location of the patient. It can also warn caregivers or family members via SMS or phone when the patient is in difficulty.

Figure 1 – Personalized Heart patient monitoring architecture

The data collected by the smart phone can be transmitted to the health care Data server via the internet. A patient can upload the data whenever the smart phone is connected to the internet via the desktop cradle/charger. This is an economic way to upload data which is not time critical. However, in case of an emergency, updates are immediately transferred to the Data server using the best available connection (e.g. GPRS). The specialist can access the Data server via secure internet access to remotely monitor the patient and if necessary update the threshold levels for the sensors. Relevant sensor data is stored in the patient's health record and can be used for further analysis.

1.1. Sensors

Data from each sensor is collected and processed in the smart phone to establish a diagnosis. For high risk cardiac patients the ECG signal is the obvious data that need to be collected continuously and should be given priority over all other sensor data. It is also important to store the ECG signal for further analysis by the cardiologist.

Detecting falls using an accelerometer is another important indication that something is wrong with the patient. Using an accelerometer and other contextual information, we can also evaluate the level of activity of the heart patient. We assess this against the heart specialist's personalized guideline and either congratulate the patient for reaching his/her goal or to encourage them to exercise a bit more. The level of physical activity recommended for a heart patient depends on his/her condition and health history. National Heart Foundation of Australia [20] says that physical exercise improves the live expectancy of heart patients and they set guidelines to help heart specialists setting a personalized level of activity for their heart patients.

We use an integrated Bluetooth ECG/Accelerometer sensor from Alive Technologies [2]. We selected this sensor since it has been demonstrated that it provides reasonably good signals for detecting normal or abnormal rhythms (arrhythmias). The Alive accelerometer has been used during a study of stroke patients at the Prince Charles Hospital (Australia) and can successfully detect falls [7]. The sensor is small (match box size) and can be easily worn without being noticed by other people.

Figure 2: Alive ECG/Accelerometer monitor (left) and A&D Medical Blood Pressure Monitor (right)

We also use a Bluetooth enabled Blood Pressure Monitor and Scale from A&D Medical [1]. High blood pressure is another important risk factor for developing cardiovascular diseases [3] and regular monitoring is essential. Also being overweight or obese can also contribute to developing cardiovascular diseases and for some heart patients monitoring the weight is important.

Finally to accurately obtain the location of a patient in case of an emergency a GPS sensor (Emtac) is used. However, GPS does not work indoors and we need to complement it with other location sensors such as the GSM Cell ID or WiFi access point locations. With GSM Cell IDs and WiFi access points we are able to provide a rough indication of the location of the patient as described in [13].

1.2. Smart phone functionalities

The application in the smart phone receives the results from the sensors and determines whether an alarm should be raised. The results of the sensors can be inaccurate due to noise and inaccurate readings. The monitoring system is only useful if we know the quality of the data we receive from the various sensors and the quality of the diagnosis based on that data. Knowing the quality we can put mechanisms in place to compensate for the lack of accuracy of certain sensors or diagnosis.

The application will therefore access the results of the sensors and if a threshold level has been reached the application needs to crosscheck whether the patient is in danger to avoid raising false alarms. In the current implementation we collect additional data from the sensor(s) and if we still measure a life threatening situation the application will seek confirmation from the user. The user can disable the alarm in case of a false alarm. If the user does not react within a certain time (currently 30 seconds) an emergency call is automatically placed. This feature is included since many patients black out or experience speech and swallowing difficulties at the time of a heart attack [3].

Since our target group will be mainly elderly people, the interaction with the monitoring application needs to be personalized and adapted to the user’s health condition. For example we need voice interaction in case the patient has bad eyesight or vibration and flashing lights for hearing impaired patients.

Furthermore, it is important to provide accurate but yet non-overwhelming information to the patient since we do not want to cause extra anxiety which would make the situation worse. For this reason we do not show an ECG diagram to a patient since we learned from discussions with cardiologists that this is a major source of anxiety for cardiac patients.

The smart phone application stores configuration data and sensor readings in a local database. Depending on the patient, the specialist can configure one or more sensors to be used to monitor the patient. The configuration section is password protected and is only accessible by a medical specialist. The monitoring frequency and what needs to be stored for further analysis varies per patient and is determined by the cardiologist. For example some cardiac patients need to monitor their sugar level as well, whereas others need to monitor their weight and blood pressure. Also threshold levels for raising an alarm differ depending on the patient’s age and condition.

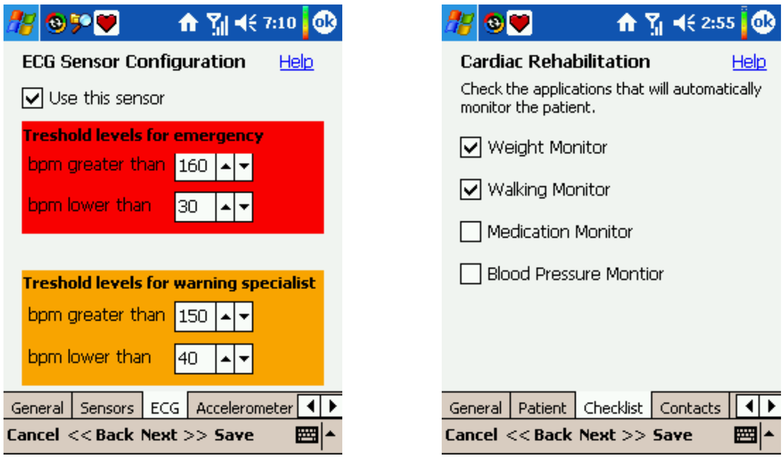
2. Prototype

We developed the application on Microsoft’s Windows Mobile Pocket PC platform. We selected this platform due to easy access to lower level APIs which are needed for the sensor modules. Also the tight integration with the operating system allows easier access to other applications running on the smart phone such as the calendar application, WiFi and obtaining the GSM Cell ID. We used the .Net Compact Framework extended with OpenNETCF [15] modules to develop the application. Data is stored in an SQL CE Server which is a compact database for mobile devices.

In this section we focus on the implementation of the ECG sensor since it is the most crucial component. ECG signals can be a source of errors which makes it hard to interpret the correct arrhythmia. In our prototype we work with a two lead ECG sensor. Noise, interference and non-rest conditions of the patient can contaminate the signal. This implies that we focus on extreme ECG signals.

In the first stage of the prototype we focus on two life threatening arrhythmias: Ventricular Fibrillation (VF) and Ventricular Tachycardia (VT). VF is a lethal arrhythmia characterized by rapid, chaotic movements of the heart muscle that causes the heart to stop functioning and leads quickly to cardiac arrest. VT is an abnormal heart beat usually to a rate of 150-200 beats per minute. VT may result in fainting, low blood pressure, shock, or even sudden death. To detect these arrhythmias we have implemented a beat detection and classifier algorithm for the smart phone.

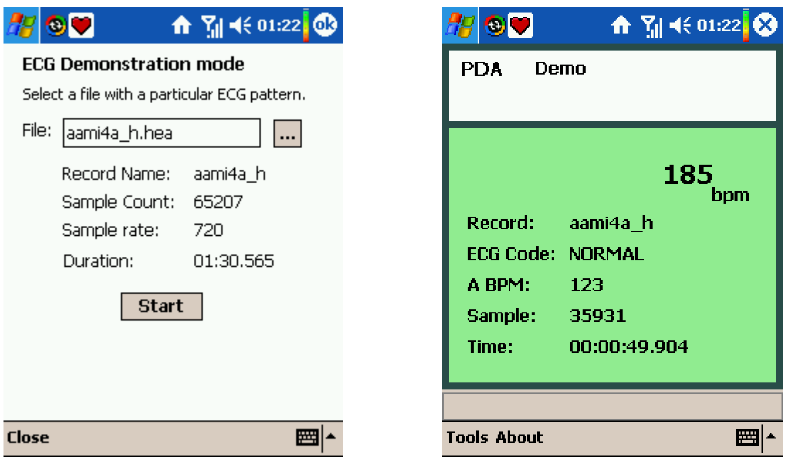
Figure 3: Screenshots ECG configuration (left) and Personalized cardiac rehabilitation configuration (right)



We used the open source heart beat detector and classifier developed by Patrick Hamilton of EP Limited [10], which is based on the algorithms developed by Pan & Tompkins [17]. The original open source implementation is in C and we ported it to C# for easy integration with the other C# software modules.

The heart beat detector and classifier is able to detect and classify a heartbeat as Normal, PVC (Premature Ventricular Complexes -extra heartbeats) or Unknown. PVCs are often harmless, but when they occur very often or repetitively, they can lead to more serious rhythm disturbances [19]. We also calculate the heartbeat rate which will be checked against the threshold levels set by the cardiologist for the patient. If the rate is too slow or too fast, the application will inform the user. If we deal with a PVC or unknown beat we record the ECG and check it for a VT/VF rhythm. We used the algorithm as detailed in [6]. If the algorithm detects either a VT or VF signal the emergency procedure is started.

Figure 4: ECG Demo mode



The heart beat detector and classifier has a sensitivity value of 99.42% and a positive predictive value of 99.51% when tested against the MIT/BIH Arrhythmia records. This is a high level of accuracy and the algorithm is also capable of processing the live ECG data in real-time. Detailed description of the performance of the heart beat detector and classifier can be found in [11].

3. Conclusion

This paper described a personalized heart monitoring application using a smart phone and wireless (wearable) sensors. We are able to detect life threatening arrhythmias locally on the smart phone and, if the patient is in danger, we can contact an ambulance automatically. In normal situations, our system monitors and records the sensor data for inclusion in the patient health record which is used for further analysis by a specialist.

Our system is designed with personalisation in mind. The heart specialist can select one or more sensors to be used for a particular patient and configure the corresponding threshold levels for that patient. Our application generates alarms or warnings when thresholds have been reached.

We process ECG and other sensor data locally on the smart phone, therefore we are able to supervise a patient without being continuously connected to a health-centre. This reduces the workload of medical staff, communication costs and motivates the patient's self-care.

Our solution is meant to monitor the patient continuously and an issue is the battery life of the used devices. The ECG sensor battery lasts for approx 60 hours. The smart phone's battery only lasts for approx eight hours when continuously connected to the ECG Bluetooth device which can be an issue if the wearer is not close to the charger (less than 10 meters). However studies show that a lot of heart patients are sedentary and can therefore charge the smart phone while being monitored.

Our target audience are patients that have had a heart attack, or are at high risk. We learned from discussions with cardiologists that these patients are worried that a heart attack will occur again. They are very motivated to wear a device that can monitor and reassure them and intrusiveness seems not to be an issue for these patients.

We believe that our system is a step towards promoting patient's autonomy and by providing personalized monitoring and advice we hope that it will give the patients more confidence and improve their quality of life.

References

[1] A&D Medical website http://www.andmedical.com.au/ [last accessed 2nd April 2006].

[2] Alive Technologies, http://www.alivetec.com, [last accessed 2nd April 2006].

[3] American Heart Association. *Heart Disease and Stroke Statistics — 2005 Update.* Dallas, Texas.: American Heart Association; 2005.

[4] Anliker, U., Ward, J.A., Lukowicz, P., Troster, G., Dolveck, F., Baer, M., Keita, F.; Schenker, E.B., Catarsi, F., Coluccini, L., Belardinelli, A., Shklarski, D., Alon, M., Hirt, E., Schmid, R.and Vuskovic, M., AMON: a wearable multiparameter medical monitoring and alert system, IEEE Transactions on Information Technology in Biomedicine, Volume 8, Issue 4, Dec. 2004 Page(s): 415 – 427.

[5] Australian Institute of Health and Welfare 2003. Secondary prevention and rehabilitation after coronary events or stroke: a review of monitoring issues. AIHW Cat. No. CVD 25. Canberra: Australian Institute of Health and Welfare. http://www.aihw.gov.au/publications/cvd/sprces/sprces.pdf [last accessed 2nd April 2006].

[6] Ayesta U., Serrano L., Romero I.,Complexity Measure revisited: A new algorithm for classifying cardiac arrhythmias, 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (2001).
[7] Boyle J., Wark T. and Karunanithi, M., Wireless Personal Monitoring of Patient Movement and Vital Signs, e-Health Research Centre, Australia, ISBN:0-86341-520-2, 2005 IEE CIMED2005 Proceedings http://e-hrc.net/pubs/abstract/RP-JB-TW-MK-wireless-pers-monitor.htm , [last accessed 2nd April 2006].
[8] Briffa T., Maiorana A., Sheerin N.J., Stubbs A.G., Oldenburg B.F., Sammel N.L.and Allan R.M., Position Statement : Physical activity for people with cardiovascular disease:recommendations of the National Heart Foundation of Australia, Medical Journal of Australia Volume 184 Number 2 , January 2006.
[9] Epi- medics, http://epi-medics.insa-lyon.fr/flash/epimedics.html [last accessed 1st February 2006].
[10] Hamilton P., EP Limited, Open Source Arrhythmia Detection Software, http://eplimited.com/software.htm [last accessed 2nd April 2006].
[11] Haryanto, R. Cardimon: A PDA based Wireless Heart Monitoring Framework, Masters Thesis, FIT University of Technology, Sydney (Supervisor: Dr. Peter Leijdekkers), August 2005.
[12] Jones, V. and van Halteren, A. and Widya, I. A. and Dokovsky, N. and Koprinkov, G. and Bults, R. and Konstantas, D. and Herzog, R. (2006) MobiHealth: Mobile Health Services based on Body Area Networks. In: M-Health Emerging Mobile Health Systems. Springer-Verlag, Berlin, pp. 219-236. ISBN 0-387-26558-9.
[13] Leijdekkers, P. and Gay, V., Personalized Service and Network Adaptation for Smart Devices, IEEE APCC Asia Pacific Conference on Communications 2005. Perth, Australia, October 2005.
[14] Myheart http://www.hitech-projects.com/euprojects/myheart/ [last accessed 2nd April 2006].
[15] OpenNETCF.org, 'The Premier .NET Compact Framework Shared Source Site' http://www.opennetcf.org , [last accessed 2nd April 2006].
[16] OSIRIS-SE Runtime Environment for Data Stream Management in Healthcare http://ii.umit.at/osiris-se . [Last accessed 2nd April 2006]
[17] Pan, J. and Tompkins, W. "A realtime QRS detection algorithm." IEEE Transaction on Biomed Eng 32:230–236. 1985
[18] PhMon Personal Health Monitoring System with Microsystem Sensor Technology http://www.phmon.de/englisch/index.html [last accessed 2nd April 2006].
[19] Premature Ventricular Contractions, American Heart association, http://www.americanheart.org/presenter.jhtml?identifier=4695 [last accessed 2nd April 2006].
[20] Physical Activity Recommendations for People with Cardiovascular Disease http://www.heartfoundation.com.au/index.cfm?page=42 [last accessed 2nd April 2006].
[21] PhysioBank, ANSI/AAMI EC13 Test Waveforms, http://physionet.org/physiobank/database/aami-ec13/, [last accessed 2nd April 2006].
[22] Rodriguez, J., Goni, A and Illarramendi, A., Real-time classification of ECGs on a PDA, Information Technology in Biomedicine, IEEE Transactions on, Volume 9, Issue 1, March 2005 Page(s): 23 – 34.
[23] Telemedicare http://www.sintef.no/units/informatics/projects/TelemediCare/ [last accessed 2nd April 2006].
[24] Ventracor pocketview, http://www.ventracor.com/ [last accessed 2nd April 2006].
[25] Vitaphone, http://www.vitaphone.de/en/ [last accessed 2nd April 2006].
[26] Welch Allyn® Micropaq, http://www.monitoring.welchallyn.com/products/wireless/micropaq.asp [last accessed 2nd April 2006].