Ubiquitous Mobile Access to Real-time Patient Monitoring Data

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Abstract

An application "Pocket WinView" was developed for a Pocket PC personal digital assistant device, which allows remote access to near real-time physiological information from a patient monitor on a commercial handheld device (iPAQ, Pocket PC). The application provides continuous display of up to six monitored physiological waveforms and parameter values. Wireless communication can be established using Wireless LAN and general packet radio service (GPRS). Data is protected with hybrid public key encryption. User authentication is required every time the application is started. Patient data can also be stored on CompactFlash memory cards for data collection purposes. Additional integration with web-based applications on the hospital intranet make it possible to combine the near real-time signals with previously recorded 12-lead ECGs, laboratory test results, and charting information.

1. Introduction

With the recent advances of Internet and wireless technology it becomes possible for physicians and care givers to remotely access patient data from anywhere and anytime. Wireless access to the patients' vital parameters and signals could greatly benefit the daily routine of caregivers, thus providing around the clock continuous intensive care (ICU) patient management in those regions where expert cardiologists/intensivists are scarce.

In the in-hospital situation, wireless access to vital signals can be particularly useful in medium care or telemetry wards, where patients may be ambulatory. Display of real-time signals is often limited to a remote screen at the nurse desk, and is not continuously available at point of care in alarm situations. In these instances, a wireless personal digital assistant (PDA) in combination with a paging system may be very useful.

2. System overview

We developed a viewing application 'Pocket WinView' for a commercially available Pocket PC PDA (Compaq, iPAQ) giving wireless access to information from the in-hospital patient monitors and telemetry transmitters. Our research set up consisted of a PDA running Pocket PC 2002/Windows CE with a 206 MHz ARM processor, 32Mb RAM and a screen resolution of 320 by 240 pixels with 4096 colors. Pocket WinView can be installed next to the existing applications and it does not restrict the PDA for personal information management such as appointments, address books, memos and other uses, including databases, e-books and calculators.

2.1. Wireless access methods

The system was designed for both in-hospital use and for off-site consultancy by physicians. Connectivity within the hospital was set up using Wireless LAN (WLAN) technology (IEEE 802.11b), which provides network speeds up to 11 Mbit/s for a limited distance (100 meters). We used several types of WLAN network cards from commercial vendors, including CompactFlash (CF) and PCMCIA cards.

For wireless connectivity outside of the hospital, a commercial cellular phone network (GSM) had to be used to ensure local coverage. However, the GSM data speed of 9600 bps appeared too low for our purposes. Therefore, a GSM/GPRS communication module was used that integrated with the PDA using a commercial expansion pack. The recently introduced General Packet Radio Service (GPRS) handles much higher speeds (up to 384 Kbps) and uses the existing antenna infrastructure of the GSM mobile network.

2.2. Data display

Pocket WinView (see figure 1) provides a continuous display of up to six monitoring waveforms including multi-lead ECG channels, systemic, pulmonary and venous blood pressure, respiratory and ventilator curves and EEG signals. Parameter values and monitor text messages including alarm conditions can also be displayed.

Initially, Pocket WinView displays the first three waveforms and four vital signs parameters from the patient monitor or telemetry transmitter. Users can customize the display by selecting other signals and parameters. Six screens have been defined, each with a specific purpose, such as a parameter screen that displays up to twelve parameters and two ECG screens that display six standard and augmented and six precordial ECG leads, respectively.

To reduce network bandwidth requirements, the waveforms and parameter data are compressed using zlib compression [1]. Data traffic was reduced to 25%. A typical connection with a bedside monitor contains 12-bit samples of at least ECG leads I and II (200/250 Hz) and the waveforms selected for display. Additionally, updates of all available parameter values such as HR and SpO2 and alarm text messages are sent.

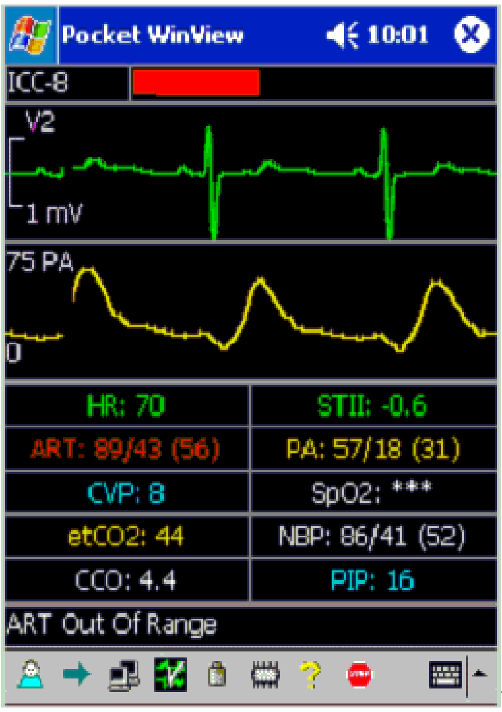

Figure 1: Screen capture of an iPAQ PDA displaying waveforms and parameter values from a patient admitted to the CCU

For displaying purposes, all waveforms were resampled to 100 Hz. The screen shows 2.4 seconds of data with a sweep speed of 25 mm/s. For certain respiratory and ventilator curves, the sweep speed can be changed to 6.25 mm/s.

The application uses adaptive buffering to provide a continuous uninterrupted stream of waveforms. On fast connections such as WLAN, the delay between the real-time data from the source monitor and the data on the PDA screen is approximately two seconds, while on slower (GPRS) connections delays are maximally eight seconds. In the latter case, the near real-time properties are not consequential, as the user is almost certainly far remote from the patient.

By default, for security and privacy issues patient names will not be displayed. Only the source monitor label and status are shown. However, users can turn on patient names if desired.

Additional integration with web-based applications on the hospital intranet also makes it possible to combine these near-real-time signals with other essential physiological information such as previously recorded 12-lead ECGs, laboratory test results and charting information.

2.3. Security

A major concern was to ensure patient confidentiality and privacy. PDA devices are small and can be easily misplaced or stolen, and the Pocket WinView application uses the public Internet and radio links for data communication. These connections are normally insecure and thus sensitive patient data could be compromised. Security threats include passive attacks such as interception of data over the Internet and active attacks such as unauthorized access to patient data. Additionally, an interceptor could theoretically modify the patient data resulting in misinformation to the off-site physician.

To address these concerns, the following preventive measures were applied:

1. Each user has to login with his/her personal account. Users are also limited to certain logical boundaries, such as the specific care unit and/or department. Users were also advised to turn on the standard password protection feature on the PDA.
2. In close cooperation with the hospital network architects, a separate Pocket WinView gateway server [2] was configured in a secure area (firewall DMZ zone) of the hospital network. Off-site connections were allowed only to this server. Additional measures were taken for protection against "denial of service" attacks and to avoid unauthorized use of the Pocket WinView connection in order to access other hospital information systems or to reach the main hospital network.
3. The Pocket WinView application uses a hybrid encryption mechanism similar to 'Pretty Good Privacy' [3]. After establishing a connection to the firewall, a 128-bit random session key is exchanged using asymmetric encryption using the Diffie-Hellman key exchange algorithm. The session key is used only once per connection and is discarded when the user disconnects.
4. User name and passwords are exchanged using the challenge, handshake and response authentication (CHAP) method [4] and the SHA1 message digest algorithm [5]. CHAP provides periodic re-authentication and can be used for additional protection against playback attacks by interceptors.
5. Conventional symmetric block encryption algorithms (AES and RC4) have been evaluated for data exchange during the session. Separate unique encryption keys are used for the up and down link. CRC32 checksums are

used for prevention of data corruption and modification.

2.4. Data storage

By expanding the PDA device with CompactFlash or PCMCIA memory cards, the near-real-time signals and parameters can also be captured and stored for later off-line analysis. With the wide availability of CF card readers for PCs, the data can easily be copied to a PC for off-line review, analysis and annotations.

Unlike the DICOM standard for image storage and exchange, there is no single standard file format for multi-channel waveform storage. We selected two well-known file formats: EDF [6] and the Physionet format [7]. A data export program on the PC converts the CF card files to EDF and Physionet compatible files, which can be reviewed using freely available viewers (see figure 2).

For exporting number and text trended parameters, a comma-separated file format was used. This file format is compatible with most programs such as MS-Excel or SPSS. In addition, we also provided a tool to save all recorded monitoring alarms (arrhythmias, limit violations).

Lastly, it is also possible to collect and store averaged 12-lead ECG-complexes and trend measurements which are computed by the patient monitor every 15-seconds for later offline review.

Figure 2: An EDF file viewer's off-line review of a recording made with the PDA data collection software

2.5. Alarm handling and smart paging

In telemetry and intensive care wards, medical device alarms may contribute to a noisy environment. A solution is to direct every alarm to the responsible nurse using a personal pager. The combination of a pager and a PDA makes it possible to provide a single device which can be used as a tool for medical calculations, assistance with reviewing of nursing protocols and intelligent alarm paging.

The gateway server is part of a system that collects the bedside-monitor alarms and passes these alarms to a centralized, intelligent paging server. This system communicates with the hospital paging system and sends paging commands using the ESPA 4.4.4 protocol. The program also handles various situations, such as redirecting alarms (based on priorities) to the next available nurse if the assigned nurse does not respond within the allowed time frame. We modified this paging system to support messaging to PDA devices. To facilitate reliable message delivery, a subset of the wireless communications transfer protocol (WCTP) was considered [8]. WCTP is a two-way communication protocol with textual and binary message content delivery through the use of a HTTP gateway and the WLAN connection.

3. Results

3.1. In-hospital setting

A pilot and usability study was held in the intensive care and telemetry ward. Test users were nurses and physicians of the intensive care ward.

It appeared that up to five active WLAN devices such as a PDA with a WLAN card could be used simultaneously. The practical operating range for a user was associated with the distance and physical makeup of obstructions such as concrete walls and steel bars between the wireless PDA and the network's wireless access point(s). Furthermore, the configuration of the PDA, expansion pack and WLAN card increased the weight and size of the mobile device and was found more cumbersome than a simple pager. The total cost of ownership of the PDA compared with a pager-only can also be significantly higher.

Integral alarm handling and paging was determined functional. However, the use in clinical practice may not be immediately accepted because of current practical issues. The wireless PDA cannot be active for a full shift, because of the reduced battery time from the relatively high power consumption of the combination of the PDA and WLAN card. Furthermore, it is currently difficult to rely on reliable message exchange when the PDA is in hibernation or in standby mode to conserve power.

3.2. Off-site remote access

The PDA was found to be convenient and useful for remote expert consulting. The GPRS expansion pack weighted less than the WLAN setup and standby time was not a limiting factor.

The GPRS network speed was sufficient for remote monitoring of a single patient. However, heavily monitored acute-level patients can still produce a 4 Kbyte/s data load even with compression and additional data reduction. We found that the public GPRS network was not always available or at times very slow. However, the GPRS network in the Netherlands has only been in operation for a short time and we expect a better quality of service as GPRS becomes widely available.

4. Discussion

By using the expanding possibilities of wireless technologies such as WLAN and GPRS, it is now feasible to use a PDA for both in-hospital and off-site wireless monitoring of vital signs and retrospective data.

The PDA appeared useful for remote emergency coaching such as electro-cardioversions and resuscitation procedures, electrophysiology and ICD testing, and haemodynamic risk stratification following primary PCI for acute myocardial infarction.

For the in-hospital setting, the wireless PDA can be useful in intensive care and telemetry wards and can extend or even replace the current paging functionality. With the expanded screen size and resolution and more memory, a paged alarm can also provide more information, such as an online review of the waveform data at the time of the alarm. Caregivers can review the vital signs at the same time, and the paging information and waveform data can be stored for later review and shared with colleagues.

In the telemetry ward, access to screens with the real-time waveforms was historically limited to viewing stations at the nurse desk. Because many patients in these wards are ambulatory, access to waveforms at the patient's location may help in providing better care. For example, during the daily routine of changing the patient's electrodes, the nurse can use the PDA to simultaneously view and check the ECG signal quality instead of having to view it retrospectively at the nurse desk.

In our preliminary experiences with the PDA in an off-site situation, we found that the system is handy and useful in combination with a separate GSM cellular phone. The cellular phone provides the mandatory interactive communication with the caregivers in the hospital. Using a wireless PDA, it is possible to handle multiple ICUs for critical care consultancy.

From a usability point of view, the limited screen size and resolution, screen clarity, PDA size and weight should further be improved. As new PDA models are regularly introduced, the manufacturers will handle most of these problems within the near future. Another improvement could be to make better use of the existing screen size and resolution by displaying the waveforms curves in "landscape" mode, thereby increasing the display width to 3.2 seconds.

Other mobile devices such as Tablet PCs can also use the wireless technology. These devices have larger screens and higher screen resolutions and can run the full range of Windows applications, including in-hospital systems such as electronic patient records, patient data management systems and viewers for different imaging modalities.

To further enhance security in the off-site situation, a virtual private network can be set up with the hospital. An intermediate step might be to evaluate using open source secure socket layer software instead of the current application layer encryption techniques.

The bandwidth and speed of wireless technology is anticipated to dramatically increase with new modalities such as WLAN IEEE 802.11a (54 Mbit/s) and UMTS (2 Mbit/s). It should in the future be possible to combine data such as the physiological vital signs and waveforms with live video images and voice communications. There are also plans to integrate WLAN techniques with cellular phone standards (GPRS); this could make it possible to seamlessly move between wireless LAN and mobile networks.

5. Conclusion

Wireless monitoring of vital signs, waveforms and retrospective data is feasible. The system offers the possibility to serve multiple ICUs for remote expert critical care consultancy, thus contributing to continuity and quality of care when 24 hours on-site expert coverage may not be available. The use of a PDA may assist in reducing the incidence of complications or medical errors and eventually reduce the ICU and hospital length of stay.

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