Intensive Care Unit Alarm Repeater and ECG Viewer on a WiFi-Enabled Personal Digital Assistant

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Abstract

The availability on the market of advanced Personal Digital Assistants (PDA) and the widespread use of reliable Wireless LANs permit the development of new solutions, which allow the improvement of medical procedures and the reduction of emergency response time. In this study, we developed a Windows CE based application, which can display real-time ECG traces, clinical data and alarms of monitored patients on a WiFi-enabled PDA device. The purpose of our study was to check whether this system could improve the standard medical procedures and decrease the emergency response time, through a usability test in ICU. The system was judged useful by nursing and medical staff. The clinical test confirmed the feasibility and usability of the system.

1. Introduction

In intensive care units, patients are monitored by bedside monitors and telemetry transmitters, and controlled by nursing and medical staff through a central station located at the nurse desk. In some cases staff cannot continuously control the central station, due to the increasing workload and the reduction of personnel. The ability to remotely access central station's data can therefore improve the medical procedures, avoiding the interruptions of routine procedures to check alarms causes. The amount of memory available in Personal Digital Assistants (PDA) and the growing CPU speed has turned such devices into powerful tools. High graphic capabilities permit to easily consult graphical information such as ECG. The presence of devices with integrated WiFi capabilities allows the development of new solutions for the improvement of mobility. WiFi enabled PDAs were therefore chosen to improve Mortara Surveyor monitoring system and make ECG traces, physiological parameters and alarms remotely available.

The usability [1,2] and feasibility of the system was assessed through a clinical test in a Care Unit and the reliability was evaluated through the analysis of connection and power status log files collected during the usage.

2. Methods

Patient monitoring system's devices are connected together through a Local Area Network. By adding WiFi Access Points, the WiFi-enabled PDA device becomes part of the monitoring network and data on the monitoring central station becomes available in real-time on the PDA device. By providing suitable radio coverage, nursing and medical staff can check critical patients status and receive alarms all the time and everywhere inside covered areas.

By adding a PC connected to the internal telephone system through a telephone interface or a voice modem, Computer Telephone Integration (CTI) services can be added to the patient monitoring system.

2.1. Development and design choices

The PDA devices were selected among the Pocket PC family. This choice was made mainly because the operating system (Microsoft Windows CE) and the development language (Microsoft embedded Visual C++ 4.0) are powerful and similar to the Personal Computer version. Two different PDAs were chosen: Hp iPaq Pocket PC h4150, due to its small size and light weight, and Toshiba Pocket Pc e800, due to a larger screen and the highest resolution available on the market. Both devices are equipped with an integrated WiFi (802.11b) adapter. Computer Telephone Integration services were developed using Microsoft Visual C++ .NET 2003. The telephone interface used was Way2Call Hi-Phone Desktop.

The Mortara Surveyor central station sends data and ECG traces to the PDA device by broadcasting UDP packets every 512ms, each one describing an 8 patients group. Each packet contains main physiological parameters (ST levels, SpO2, HR, Temperature, Invasive and non Invasive blood pressures), patient name, description of alarms and ECG traces (1 lead per patient,

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512ms per packet, 125 samples/s resolution). The use of the UDP protocol permits a very low bandwidth usage (about 360 bytes/s per patient) and little overhead for the transmitting station.

The main aim in developing the graphical interface was to achieve a high ease of use, so that the device could be used in an intuitive manner without long trainings. For this reason the graphical style and the alarm sounds were made similar to the Monitoring Central Station ones. For the same reason the device is fully controlled through the hardware buttons, avoiding the use of the stylus. All functions are described by icons placed near the corresponding hardware button.

2.2. Functions

The PDA device displays two frames with real-time ECG traces and parameters banners of two patients, as well as a list of patients with (if present) alarms description. The first frame is automatically set to the patient with the highest priority alarm, while the second one can be chosen within the patients list through the navigation buttons or the stylus. Below each ECG trace a scrolling banner displays physiological parameters, while patient name, bed number, hearth rate and lead name are shown in the ECG frame, together with the description of the alarm (if present). In the lower part of the screen four icons are displayed near the hardware buttons to describe the functions performed by each one.

When an alarm occurs, the first frame is automatically set to the corresponding patient and a warning sound is produced. By pressing a hardware button, the user can silence the local alarm but not the central alarm; this state is indicated by a different colour combination. The first frame will automatically switch to the next patient in alarm (if any).

In QVGA (240x320, 96 dpi) equipped devices the resolution was halved (2 samples per pixel) to achieve an acceptable trace length. In devices with VGA (480x640, 192 dpi) displays the full resolution was kept (1 sample per pixel).

Figure 1: Traces on a QVGA (upper) and VGA (lower) device.

The devices can be used with two different orientations. In Portrait mode, with vertical orientation, 3,38 seconds of ECG trace can be displayed, together with alarms states of 8 (10 hiding the descriptive icons) patients at the same time.

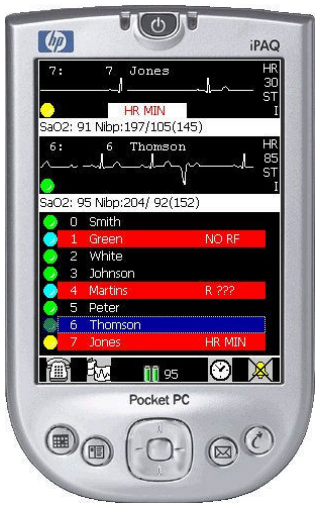

Figura 2: Layout in Portrait mode.

In Landscape mode, with horizontal orientation, the length of ECG traces is increased to 4,24 seconds (4,66 hiding the descriptive icons), but it's possible to display alarms states of only 5 patients at the same time.

Figure 3: Layout in Landscape mode.

The change between portrait and landscape mode requires a soft reset on Windows Mobile 2003 based PDAs (like Hp iPaq Pocket PC h4150). On PDAs running Windows Mobile 2003 Second Edition (like Toshiba Pocket Pc e800) the screen orientation change can be performed on the fly.

The disconnection from the monitoring central station occurs when the device doesn't receive UDP packets for a configurable time and is signaled by an alarm sound and a warning on the display.

The battery charge level is displayed through an indicator and low levels are signaled by alarm sounds.

2.3. Advanced functions

Other three functions were developed besides the ECG

viewer and alarm repeater capabilities.

The user can send a print request for the patient currently selected to the monitoring central station by pressing a hardware button.

The device stores a list of old alarms for each patient, specifying alarm description and time, that can be shown by pressing an hardware button.

The last function, performed by a Personal Computer connected to the internal telephone system through a telephone interface, allow the user to automatically send support requests to medical staff's phone or pager during emergencies. For example, a nurse can call a doctor by pressing a hardware button on the PDA; the system automatically establishes a phone call to doctor's telephone. When the doctor answers the phone, alarm details are described using recorded messages. When the message ends, the doctor can record a response message that will be played on the PDA and heard by the nurse. Different procedure stages and line states are described on the PDA through recorded messages; the nurse can thus continue to perform emergency procedures and be warn if the call fails without watching PDA's screen.

2.4. Evaluation method

The system was tested in a Care Unit of a small community hospital equipped with a Mortara Surveyor monitoring system consisting of 4 Surveyor monitors, 4 X-12 telemetry transmitters and a Surveyor Central monitoring central station. Two Linksys WAP11 802.11b WiFi Access Points were added, together with a Personal Computer connected to the internal telephone system through a Way2Call Hi-Phone Desktop telephone interface. Two different PDAs were used: HP iPaq Pocket PC h4150 and Toshiba Pocket PC e800. The WLAN covered the whole department and part of the neighboring ward (personnel was shared during the night).

Both medical and nursing staff tested the system for two weeks. The staff was not trained in the use of the system; only a brief description of different functions was provided, in order to assess the ease of use of the Graphical User Interface. The system usability and effectiveness in reducing emergency response time and improving medical procedures were assessed through interviews.

Hp iPaq Pocket PC h4150 PDA was used with two swappable batteries to allow a continuous use of the system.

To perform Computer Telephone Integration (CTI) services, the application on the Personal Computer was adapted to the internal one-way paging system. Following a support request, it was only possible to play a recorded message on the pager for a configurable number of times, due to the limited paging system. The system was only able to check whether the line was busy and warn the nurse with a recorded message on the PDA.

3. Results

The system was stable and reliable. Unrecognized disconnections and accidental shutdowns didn't occur, therefore the alarms repeater function proved to be reliable. Small interface changes were requested and implemented during the evaluation period. The printing function exhibited an error and was disabled for the rest of the test. The internal one-way paging system limited the potentials of CTI services, but was tested and appreciated by nursing and medical staff, although no emergencies that required a support request occurred.

3.1. Usability

The system was judged intuitive and easy to use from the beginning. The possibility to fully control the device through hardware buttons without using the stylus was very appreciated. The HP iPaq Pocket PC h4150 was preferred, due to its small size.

The battery duration (approximately 2 hours and 45 minutes of continuous usage) was judged adequate. No shutdown caused by low battery level occurred. By using two swappable batteries it was possible to use the system continuously.

After the introduction of the system in the ward, nursing and medical staff modified several procedures. Some are described in the following:

- During night shifts, nursing staff is shared with the neighbouring ward. Each time an alarm occurred, a nurse had to reach the monitoring central station, check the alarm and eventually reach the patient even if he's near patient's room. By using the PDA, personnel can hear clearly the alarm on the PDA and check it while reaching the patient.
- During telemetry patient's visit, medical staff couldn't consult real time ECG. If an emergency occurred or the doctor needed to check the ECG during a medical procedure, it was necessary to use a portable monitor. By using the PDA, medical staff can check telemetry patient's ECG everywhere inside the coverage area.

3.2. Roaming and connection

The roaming procedure, necessary for switching between Access Points during the transition from one coverage cell to another, is present in Toshiba Pocket PC e800 (Wi-Fi [3] certified product) but not yet implemented in Hp iPaq Pocket PC h4150, therefore an ad-hoc software was developed to perform roaming tasks. The roaming procedure takes about 10 seconds on Hp iPaq PDA, while Toshiba PDA requires from 5 to 15 seconds.

The roaming procedure failed and PDAs remained disconnected rarely. The system reconnected, after switching the device off and on, in about 10 seconds. This issue was more frequent on Toshiba PDA, and it was probably caused by an imperfect implementation of roaming procedure in Linksys WAP11 Access Points. A problem in PDA's roaming implementation cannot be excluded, since patches are frequently released to improve roaming performances.

Information about connection status and packet loss was obtained through log files analysis. Following considerations are based on the analysis of Hp PDA's logs collected during 7 days, 17 hours, 13 minutes and 36 seconds of use.

The occasional loss of packets should be considered normal, since data is sent by broadcasting UDP packets, and doesn't jeopardize the synchronization between PDA and Monitoring Central Station. Each lost packet causes a gap of 512ms in ECG traces and a delay of 512ms in the notification of alarms occurred during the loss (worst case). 96,68% of loss events regarded less than 4 consecutive packets, causing a maximum gap of 1,53 seconds. These events, that can occur during normal use, caused the loss of 2,82% of total data, with on average a gap of 604ms every 21 seconds.

The loss of a number of consecutive packets between 4 and 16, with decreasing exponential shape, is caused by decreasing signal strength. These events caused an average gap of 2,8 seconds during the use in low signal strength areas, causing the loss of 0,37% of total data.

The loss of a number of consecutive packets between 17 and 24, with Gaussian shape with maximum at 20 consecutive packets, is caused by the roaming procedure and caused an average gap of 10 ±1,8 seconds (confidence interval 95%) and occurs during the transition from one AP coverage cell to another.

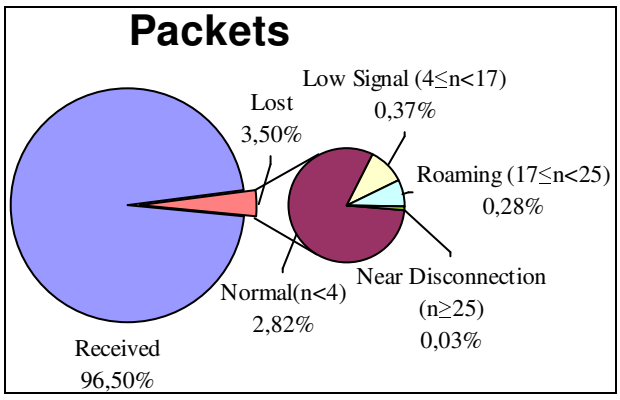

Figure 4: Connection analysis.

The total amount of lost data was 3,5%.

4. Discussion and conclusions

The clinical test confirmed the feasibility and usability of the system. Medical and nursing staff improved some medical procedures and reduced the number of interruptions in standard procedures by using the system.

The roaming time, even if judged acceptable from nursing and medical staff, can't be considered satisfactory. An in-depth study of WiFi network is therefore necessary to assure a fast roaming transition and resolve the disconnection issue. A thorough planning of WiFi network installation is moreover of primary importance to obtain a reliable mobile alarms repeater.

Although no accidental shutdown occurred, the power button is not protected and involuntary shutdowns are possible. A way to disable the power button must therefore be implemented.

The Computer Telephone Integration services were not thoroughly tested, due to the old one-way paging system used in the hospital. A modern two-way paging system can make the most of system potentials and will be tested. The printing function issue will soon be fixed.

Further clinical tests are indicated to assess the system usability in different kind of ICU and to better meet nursing and medical staff requirements.

Acknowledgements

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