Internet Based Remote Patient Monitoring and Diagnostic System

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Abstract – **In this paper we present a remote patient monitoring and diagnostic system, using a combination of fieldbus and Internet networking technologies. The bedside devices are connected via an industry standard fieldbus. This network is linked to the Internet by a gateway, allowing easy access to the acquired data. The system developed allows healthcare professionals to follow the state of patients through a simple browser. Electrocardiogram measurements, arterial blood pressure, body temperature, abdominal air pressure or nasal airflow and other optional vital signals are transmitted in real time from the patient to the medical staff at remote locations. Centralized system management, industry standard off-the shelf components and open source software cut down costs and give hospitals significant freedom.**

I. INTRODUCTION

Medical applications of computerized data transfer range from administrative tasks, such as patient record transfer, to real-time vital function analysis as seen in bedside monitoring and diagnostic systems. While the former services are forgiving in terms of network specification, the latter can be very demanding.

Modern in-patient monitoring systems installed in intensive care departments offer networking between several bedside units and a central monitor, typically found on-site. Unfortunately the interoperability of these products are somewhat bounded. The systems are generally unique applications which do not make use of widely available Internet Protocol (IP) based networks. To make the most advantage of network services, it is indispensable to have a freely available, open standards based system, to which it is easy to connect, is easily expandable, while fulfilling every requirement related to remote patient diagnostics, teleconsultation and remote patient monitoring.

But why are IP based telemonitoring and diagnostic systems different? The Internet has now became universal along with the primary and quasi-universal user interface, the web browser. Telemedicine has seen a rapid evolution in recent years. Optical communication backbones and digital subscriber lines are becoming more and more common in bigger cities – not to mention maturing mobile technologies. These networks generally offer IP based services, their usage is transparent thanks to openly and freely available standards. Therefore there is a very high interest in research to provide benefits to both the patient and the medical staff using these new technologies. Hence the next logical step was to create a monitoring, analysis and diagnostic system for intensive in-patient care accessible through the Internet.

II. CONSIDERATIONS IN VITAL FUNCTION MONITORING AND DIAGNOSIS VIA INTERNET

Patient monitors are no longer only displaying the patient's vital functions besides the bed, but are also data collecting communication devices sending measurement data to off-site centralized monitoring, data processing and archiving sites. Despite the advances in the field, two paradigms were left untouched: today the majority of the applied in-patient monitoring systems are based on proprietary, closed architectures and are not using open standard interfaces [1]. Our research goal was to establish an Internet Protocol enabled bedside monitoring system bearing the following attributes:

1) Make use of the open architecture prototype remote patient monitoring system implemented in the Biomedical Engineering Laboratory at the Department of Control Engineering and Information Technology of the Budapest University of Technology and Economics [2].
2) Use of open standards and open source software.
3) Keep further development easy.
4) Maintain reasonable system costs.

III. METHODS

In order to achieve our objective to create an Internet based telecare system, we used a blend of two different data transfer technologies: an industry standard fieldbus and a widely available IP capable Ethernet network. While the fieldbus provides the robustness and reliability considered paramount in healthcare, the Ethernet delivers easy access to the information about the patient.

A. Bedside network using industry standard fieldbus

Although there exists some vendor specific communication interfaces, there is no complete standard available to date which is suitable for an open architecture bedside monitoring system. The best candidate is the Medical Information Bus (MIB, IEEE P1073) [3], but it is still under heavy development, and therefore it is limited to the lower communication layers and is still incomplete. In order to meet the requirements set by an open architecture and scalable system, we turned to a communication standard from another field, which is readily available and which fulfills our needs.

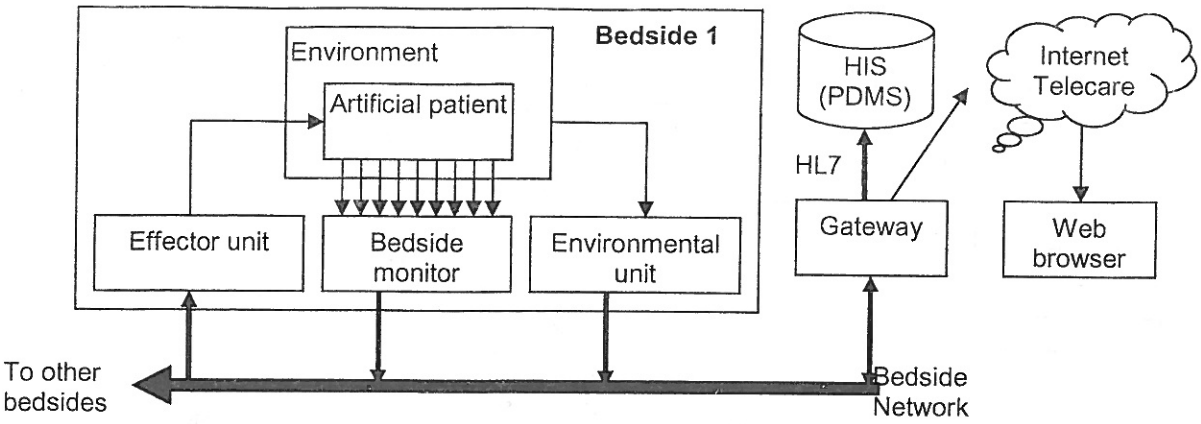

Fig. 1. Bedside Network

Conditions imposed on industrial communication standards, or so-called fieldbus systems, are strikingly similar to the terms required by the medical bedside communication systems. The industrial need for deterministic, fault-tolerant operation and exact timing yielded several fieldbus communication protocols and hardware devices.

Our choice fell on the Profibus DP fieldbus standard, which supports time critical, robust, cyclical data exchange at a reasonable speed. It also supports interconnection redundancy, with data exchange speeds up to 12 Mbit/s. The Profibus DP protocol is a master-slave protocol which allows multiple masters on the same bus. The arbitration between the masters is provided by a logical token ring. Profibus DP specifies a fully standardized data transfer protocol with very strict timings. It allows plug-and-play installation and hot replacements of bus devices. When using a twisted pair two wire cable at 1.5 Mbit/s, the maximum segment length can be 120 meters. Theoretically a maximum of 32 devices can be connected to the segment.

Although being sufficiently open and being readily available, the 1.5 Mb transmission speed supports the traffic generated by at most 16 slave modules, each being dedicated to a bed. This is enough for a hospital room, but it is clearly in short to be deployed in its current form in an entire hospital.

In order to develop the monitoring system, an appropriate source of signal was also needed. This had to resemble to the closest possible degree to a real patient, whose vital parameters are measured using electrodes and catheters. To eliminate the inconveniences posed by real measurements on humans during the development, an Artificial Patient was used, as seen on Fig 1. The substitute was a PC with a digital-to-analog (DAC) interface card, which was fed by a multichannel reference signal [4] and which gave a 0..5 V range output signal at a 12 bit resolution, thereby conforming to strict safety regulations.

The Bedside Monitor itself was realized with an 80386-based single board industrial panel PC. The generated vital signals were measured by an 8-channel analog to digital converter (ADC) card at 12 bit resolution. The sampling rate was 100 Hz in the case of the ECG and blood pressure signals and 50 Hz in the case of the other signals. As the selected industrial panel PC had no direct fieldbus communication interface, we used an external fieldbus link module, which can act as a gateway between the Profibus DP and the RS232 serial port of the panel PC. The Actuator and Environmental Units are digital and analog input/output units connected to the Profibus to eventually control room temperature, nurse calls etc.

B. Services made available through the Internet

Having a bedside monitor providing data, we needed to ensure that the data derived from patient's vital functions is made easily accessible. Therefore we connected the fieldbus based system to a PC acting as a Gateway, relaying data between the two networks, as seen on Fig. 2. The bedside monitors (bus slaves) send data to the PC (acting as bus master) which, besides containing a DP card, also has access to an IP based network via an Ethernet adapter, resulting in a server able to deliver patient data to its clients on the Internet.

Data transfer taking place on the fieldbus is controlled through shared object (so) library calls. The library is implemented in platform independent ANSI C, and currently it compiles under UNIX and Windows environments. Each bedside unit must be initialized and properly configured at power-on. Relevant parameters can be stored in a SQL database, with a simple web-based user interface to set the proper values. Data packets are seized using 100 ms polling cycles, also by using the application programming interface (API) of the so library. Once the readings are obtained, they are transmitted to the data converting and relaying server through a standard TCP socket. While TCP can prove to be quite reliable, the underlying simple Ethernet layer should not be considered to be sufficient to fulfill hard real-time demands. By distributing server load, stock Ethernet has not shown any limitations in our prototype testbed.

The Data providing and converting server has the primary role to convert all acquired data to a standards compliant format. Having a well defined data structure, by using a standard TCP connection, and given that all source code is freely available, it easy to integrate the in-patient monitoring system to any arbitrary HIS.

Database and Web servers ensure that valuable information can be accessed anywhere or stored at a dedicated archiving site for future reference. The Web server is used to run an Apache https server which serves the graphical end-user interface (GUI) JAVA applet.

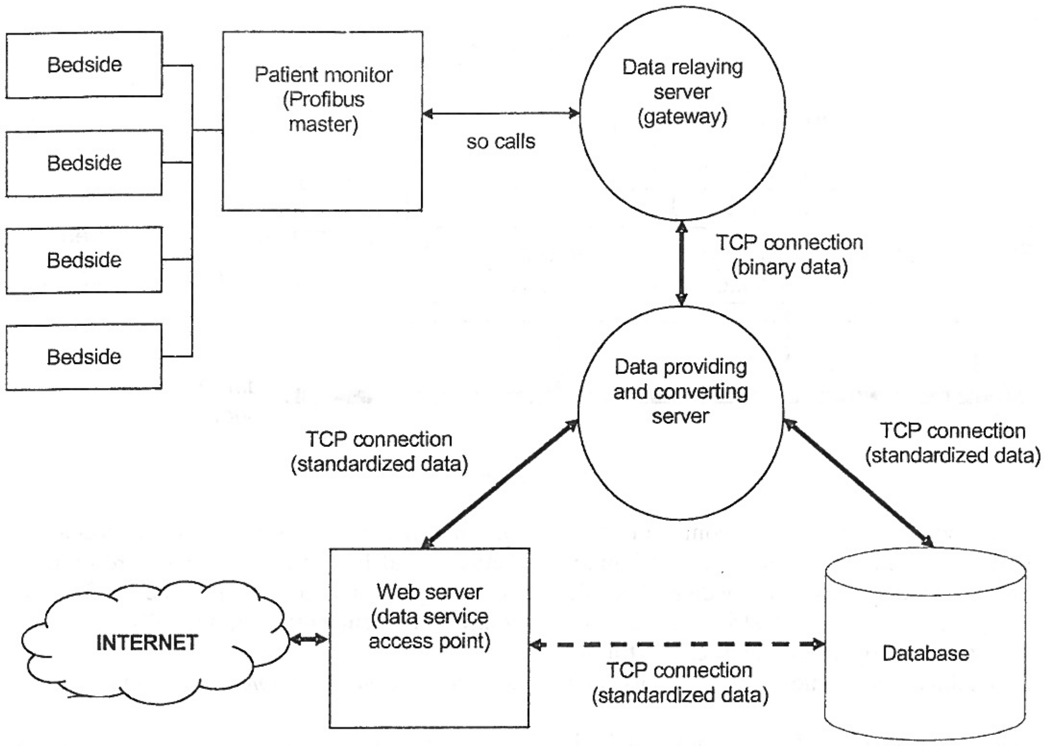

Fig. 2. Architectural overview of the full network

Finally all in-patient monitor readings and settings can be accessed using only a simple web browser on any platform with JAVA support. No client-side configuration is needed, significantly reducing deployment and maintenance costs. Data is kept confidential using secure connections with the same degree of reliability as offered by current online banking and e-commerce sites.

IV. RESULTS AND DISCUSSION

The prototype of the remote patient monitoring system was implemented in the Biomedical Engineering Laboratory at the Department of Control Engineering and Information Technology, Budapest University of Technology and Economics.

The system was built only by using free software – with the exception of the Profibus DP adapter interface-card's kernel loadable module device driver, which was provided by the manufacturer. The meaning of the word free in free software does not mean that it doesn't cost anything – it should rather be interpreted in the sense as in freedom. Linux and Open Source software is gaining momentum in biomedical applications [5], because it is cheap, robust, gives people the freedom to tinker and is generally less plagued by the security problems that haunt Microsoft Windows. Having all source code readily available and modifiable without license fee limitations permits the user to have hands-on, full access to the system: therefore the goals of easy integration and further development can be easily met. The wide use of Open Source software in medical informatics is not a common place in our day – despite the fact, that Open Source has been around for over thirty years. There are at least six larger Open Source medical informatics projects, but most of them deal with medical and patient records (such as registration, scheduling, billing etc.) and do not concern medical applications such as in-patient monitoring.

The bedside monitor transmits both the primary and the derived signals in real time to the central monitor. The cyclical data transmission is scheduled by the fieldbus master (the data relaying server) in 100 ms cycles. The environmental and actuator signals (such as a light switch) are exchanged with the corresponding I/O units using a 1000 ms polling cycle.

The crucial points of the system performance are the capacity of the used bedside network and the robust handling of various network failures. The 1.5 Mb/s transmission speed of the single-master bedside Profibus DP network allows approximately 100 kbytes of user data transmission per second. The real-time transmission of the measured vital and environmental signals of one bedside requires less than 5 kb/s. Therefore, the fieldbus network is able to interconnect the data relaying server with up to 16 bedside monitors. The evaluation and verification of the system was carried by using an additional desktop computer as a fieldbus data traffic and bus load monitor, which was equipped with a Profibus master slot card.

The present installation with one bedside results in 4% network traffic load measured by the bus load monitor. The network data traffic of the other 15 bedsides was simulated by a Profibus bus load simulator device [6]. In this case, the total bus load (altogether 16 bedsides) increased up to 75%. The bus-load simulator also proved to be helpful to simulate various network failures, e.g., data losses due to device malfunctions and fieldbus errors. The data transmission performance of the still active bedside monitors was not affected by the failed bedside monitors as far as the master remained active. This result was provided by the underlying Profibus DP communication technology, which fulfilled the preliminary expectations.

The standard 100 Mb/s Fast Ethernet (IEEE802.3) adapter on the IP based switched local area network (LAN) relayed with ease the traffic generated by the Profibus loaded via simulation. It should be stated, that the system in its current form can be considered reliable only to the extremity of the fieldbus, since there is currently no technology available to deliver reliable real-time IP based large networks. Reliability of the prototype developed can be somewhat further enhanced by using software solutions – at the eventual expense of degrading performance. On the other hand, it might be worth considering to wait for the deployment of industrial, real-time Ethernet devices, which have also started to appear at the horizon.

Along the improvement of reliability over general public IP networks, there is room for other further research with eventually more promising results [7]. The capability to process captured measurement data online, on off-site computing facilities and to store captured data remotely, gives us the ability to be able to significantly surpass the capabilities of traditional, so-called first and second generation systems. Although the latter have reliable signal interpretation capabilities, such as border value alarm triggers, cardiac and respiratory arrythmia detection, more resource intensive services will be available in the near future, like eventual decision support based diagnostics and other higher level signal interpretation requiring large resources.

V. CONCLUSION

A new and alternative way for the development of patient monitoring systems has been proposed: industry-standard system components and fieldbus communication technology. The novel approach of using industry-standard off-the-shelf solutions resulted in a scalable design at a reasonable development cost and increased the flexibility and maintainability of the patient monitoring system. The main benefit of the system from the signal interpretation point of view is in the design of the data streaming architecture. The data relaying server allows the real-time access of bedside data via standard software interfaces, so the upgrade of the signal interpretation layer can be realized without affecting the other components.

The feasibility of proposed system was verified by the implementation of a prototype system. The performance evaluation and system design verification have shown that the system is capable of robust handling of up to 16 bedsides per hospital room. Although the system design neglects some of the real aspects of patient monitoring (i.e., the real vital signal properties and ranges, strict standards for patient safety), it provides a fair and flexible demonstration of the complex problem of patient monitoring.

ACKNOWLEDGMENTS

This research and development project has been supported by the Hungarian National Research Fund grants No. OTKA F046726, OTKA T042990, by the Hungarian Ministry of Education grant No. FKFP 0200/2001, and by the Joint Hungarian – Romanian Intergovernmental S & T Cooperation Program grant No. 09/2002.

VI. REFERENCES

[1] Hewlett-Packard Company, Medical Products Group Headquarters: 3000 Minuteman Road Andover, MA 01810

[2] P. Varady, Z. Benyo, B. Benyo: "An Open Architecture Patient Monitoring System Using Standard Technologies", IEEE Trans Inf Technol Biomed., Vol. 6. pp. 95 – 98, March 2002.

[3] MIB (IEEE P1073): Official MIB home page for the Institute of Electrical and Electronics Engineers (IEEE): http://stdsbbs.ieee.org/groups/mib/index.html

[4] G. B. Moody and R. G. Mark, "A database to support development and evaluation of intelligent intensive care monitoring," Comput. Cardiol., Vol. 23, pp. 657–660, 1996.

[5] C.J. McDonald, G. Schadow, M. Barnes, P. Dexter et al.: "Open Source software in medical informatics – why, how and what" Int J Med Inf. 69(2-3) pp. 175 – 184, March 2003.

[6] M. Heinz: "Buslastemulator für profibus" diploma thesis, Institute of Computer Technology, Technical Univ. of Vienna, Austria, 1996.

[7] J. Sziray: "Verification and Validation of Software Systems", INES 2002, 6th IEEE International Conference on Intelligent Engineering Systems 2002, May 26-28, 2002, Opatija, Croatia, ISBN 953-6071-17-7, ISSN 1562-5850