Web-based Real-time Remote Monitoring for Pervasive Healthcare

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***Abstract*—the goal of the CARA (Context-Aware Real-time Assistant) healthcare architecture is to enable improved healthcare through the intelligent use of wireless remote monitoring of patient vital signs, supplemented by rich contextual information. One of its applications currently being deployed is the remote live monitoring of a patient by a healthcare professional. The vital signs are monitored using a wireless BAN based on sensors that can monitor position in space, ECG, blood pressure, and blood oxygenation. A design goal of ubiquitous access means that all communications are performed using recent web technologies, thereby minimizing issues with firewalls and facilitating remote ease of access. The only tool required for this application is a web browser with the commonly-available Adobe Flash plug-in installed. Thus remote monitoring, independent of geographic location, is possible form any computer or suitable smartphone. Important aspects of this application include: inter-visibility between patient and caregiver; real-time interactive medical consultation; and replay, review and annotation of the remote consultation by the medical professional. The annotation of significant parts of the multi-modal monitored signals by the medical professional provides the basis for the automated intelligent analysis of the CARA system. The paper discusses the application in the context of the overall CARA healthcare architecture, and presents results of some experiments using the application.**

Keywords- Pervasive Healthcare, CARA, Remote Monitoring, Web Technologies

I. INTRODUCTION

The increasing elderly population in many countries brings a need for more healthcare options. Increased life expectancy has led to the median age being pushed higher, thus resulting in an increased proportion of senior citizens. In general, senior citizens are more vulnerable to chronic diseases, requiring medical care, than the rest of the population. McDougall [1] claims that in Europe, the proportion of the population greater than 65 is projected to increase from 12.4% in 2000 to 19.6% in 2030 which translates into an estimated 71 million elderly by 2030. This increase will have a direct impact in health-care institutions, specifically considering the fact that the health-care costs per capita for persons over 65 years are three to five times greater in comparison with the health-care costs of persons under 65. To address the rising costs, the public financing of long-term care for the period 2000–2020 is projected to increase 20–21% in the UK and the US, while this figure in Japan is estimated to be 102%.

When considering the above figures it becomes evident that the provision of effective healthcare services is of critical importance to the social and economic welfare of every country. Therefore, various telemedicine and healthcare projects have been actively planned and promoted in recent years. Telemedicine, as described by Istepanian [2], mainly utilizes telecommunication technology to provide various remote healthcare services such as medical diagnosis, treatment, education and healthcare for patients.

In this paper we present the CARA pervasive healthcare architecture, with the focus on its web-based remote monitoring application. The main components of the CARA system are:

1. Wireless Monitoring Device (WMD)

This is a key component of the Body Area Network (BAN), and includes medical sensors such as the ECG, SpO2 meter, temperature sensor and mobility sensor. The WMD plays a central role in health monitoring and in the emergency detection functionality of the system.

2. Home Monitoring System.

This is aimed at helping the elderly to live autonomously at home. A web camera is integrated to this system that may be used for monitoring and for interaction between the elderly and the carer.

3. Remote Clinical Monitoring System.

This is responsible for remotely controlling the BAN and continuously monitoring physiological signals of the elderly via an internet connection. Furthermore, real-time data obtained from BAN are recorded on the server for further reviewing and analysing.

4. Healthcare Reasoning System.

This is implemented by a reasoning engine, and applies medical rules, appropriate for the individual, to real-time data that is received from the vital sign sensors.

The CARA system can be used in different ways, varying from fully automatic analysis of real-time patient vital signs resulting in automated response, to a non-automatic assistant for remote real-time clinical analysis by a specialist. The latter use of the system is the more viable currrent use of the system, as it avoids the inherent problem of data errors in wearable sensors, and also avoids the medical, legal and social issues associated with new models of automated intelligent healthcare.

II. RELATED WORK

An early method of remote monitoring of physiological signal involved analogue transmission over telephone lines [4], [5], [6], and [7]. This approach involves the modulation of physiological signals to audible frequencies before transmission over the public switched telephone network [8].

Although these systems allow for real-time monitoring, they are constrained by poor bandwidth to a limited number of channels, incur high telephone charges when used long distance, and suffer from signal degradation due to noise. Because of the fast development and popularity of the internet, the telemedicine applications to provide long-term monitoring and healthcare by transmitting personal physiological information via the internet have become highly feasible.

Khanja et al. [9] describe the development of a remote monitoring system for ECG signals. The system provides remote monitoring of several patients wearing a portable device equipped with ZigBee module connective based on wireless sensor networks. The system records data to an on-line database, and the ECG signals are analysed on a server.If serious heart anomalies are detected an alarm is sent to authorized medical staffs or to the physician through the telecommunication network.

Cheriyan et al. [10] present the design of an embedded system which is capable of tracking relevant bio-signals from the person in real time and facilitating a dependable decision making process that provides alerts for potential brain activity changes. The design focuses around the use of sensors and a processing element. It incorporates the use of electroencephalography (EEG) and oxygen saturation (SpO2) signals.

Capua et al. [11] present an original ECG measurement system based on a web-service-oriented architecture to monitor the heart condition of cardiac patients. The projected device is a smart patient-adaptive system able to provide personalized diagnoses by using personal data and clinical history of the monitored patient.

III. SYSTEM OVERVIEW

The advances in internet technology have made possible innovative methods for the delivery of healthcare. Universal access and a networking infrastructure that can facilitate secure sharing of patient information and clinical data, make the internet an ideal tool for remote patient monitoring applications.

An overall architecture of the CARA healthcare system is shown in Figure 1. At the core of the system is the user, also referred to as the "subject" (in a research environment) and as the "patient" (in a clinical or therapeutic environment). The user is monitored by sensors and prompted by actuators, within a wireless body area sensor network, often referred to simply as a body area network (BAN). This is referred to as Tier 1.

The information gathered by the components of the BAN is sent to a gateway (often a PC or a smart phone). This is referred to as Tier 2. The communications links used between the BAN and the personal server will vary according to circumstances.

The gateway connects over the internet or other long range communications protocols to various Tier 3 services. These may include a medical server, a healthcare provider, a researcher, a caregiver, emergency services, and so forth. An Adobe Flash application running in the gateway publishes data along with live video streams to the CARA server. On the server side, the system stores derived data obtained from the sensor data in an implementation independent generic format (i.e. XML), and keeps the records in an embedded database. As a part of the system, the reasoning or rule engine is developed and deployed on the server-side as an intelligent agent; it is designed to help decision-making on alerts as a reactive system. The medical consultant logs into the flash application remotely and selects the appropriate patient. The application then provides the consultant with continually updating views of the real-time readings. Additionally, the consultant can also review the previous readings recorded on the server. Having analysed the recorded patient data, they can then issue a clinical report containing their findings.

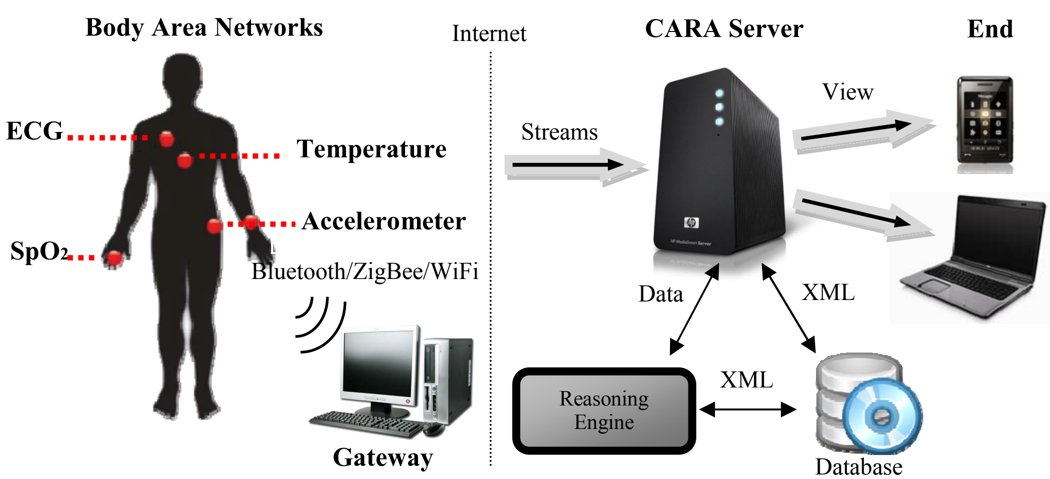

Figure 1. CARA system architecture.

IV. SYSTEM IMPLEMENTATION

As we had mentioned in the previous section, the CARA system is composed by four main parts:

A. Body Area Network (BAN)

The Wireless Monitoring Device (WMD) is based on a BAN is developed by Tyndall Institute of University College Cork. The sensor platform is a 25mm×25mm module comprising the interfaces to the various sensors along with an Atmel AVR Atmega 128 micro-controller and a Nordic RF2401 Transceiver. The WMD not only receives physiological signals, but also transfers the physiological data through the wireless network to the CARA server, so that complete and continuous personal physiological records can be kept.

B. Home Monitoring System

The Home Monitoring System aims to support independent living at home for the elderly. It is based on the WMD and a web camera and uses Flash Media Live Encoder to capture live video and stream it to a Flash Media Server [12].

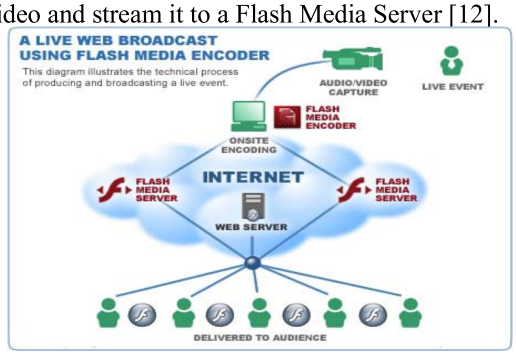

Figure 2. Live web broadcast using Flash Media Server.

Figure 2 shows the live web broadcasting. The reason we integrate live video communication into the CARA system is to let the caregiver have a direct real-time view of the patient and surroundings so that they can communicate directly with the patient, interpret any spurious readingsand avoid misdiagnosis. Continuous monitoring is carried out by caregiver remotely while the subject is wearing the WMD. When the data is received, the system analyses it in real-time by activating observation patterns.

C. Remote Monitoring System

The Remote Monitoring System is designed as a web application for physicians to monitor patients remotely. In traditional web applications, there is a limit to the interactivity that can be added to a single page. Once the on-page options are exhausted, the user has to refresh the page and a new page is downloaded. This often leads to delays, during which time the remote consultant may get tired of waiting. With RIA (Rich Internet Applications) technologies, the client computer and the server can communicate without page refreshes. In this way, web applications can support more complex and diverse user interactivity within a single screen. Requested information appears on the same screen upon which information request was registered. This allows real time user interaction which satisfies the main requirement of our system. Besides increased user interactivity, RIA technologies have also redefined the use of graphics, sound and animations in revitalizing the user interface. RIA technologies offer more options for designing a visual interface. Graphic formats designed using RIA technologies use network bandwidth sparingly. With RIA, designers can use more graphics and sound throughout the website. Rich Internet Applications are an entirely new experience for the end user. Flex is one of the latest technologies in the realm of Rich Internet Applications. It was chosen for its ubiquity since it is estimated that over 90% of web users now have the Flash Player installed on their computers The application is implemented in Adobe Flex and FluorineFx.Net which is basically a flash application working under the ASP.Net environment. In order to launch the application, the user must first log into the web application hosted on the server by providing a user name and password. Upon successful login, the user is presented with a user interface shown in Figure 3.

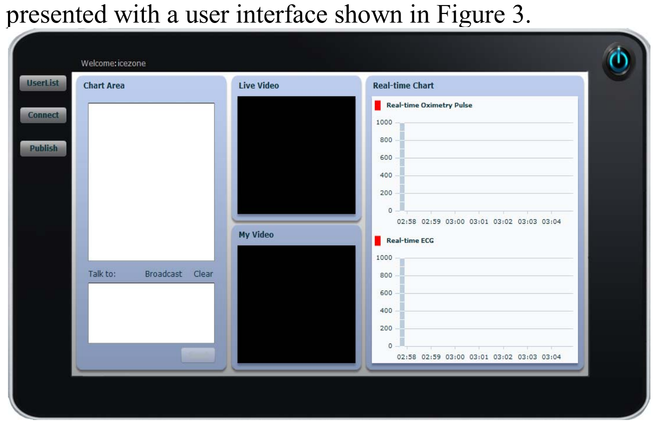

Figure 3. Interface of the Remote Monitoring System.

By clicking user list button, the list of the online users currently available on the server will pop up. Once the WMD is set up properly, the application starts receiving data from WMD through wireless communication. Data can be transferred to the CARA server using the AMF [13] (Action Message Format) protocol if the user clicks the publish button. A caregiver in a remote location can log into the application and view the graphic readings by selecting the patient in the user list (See Figure 4).

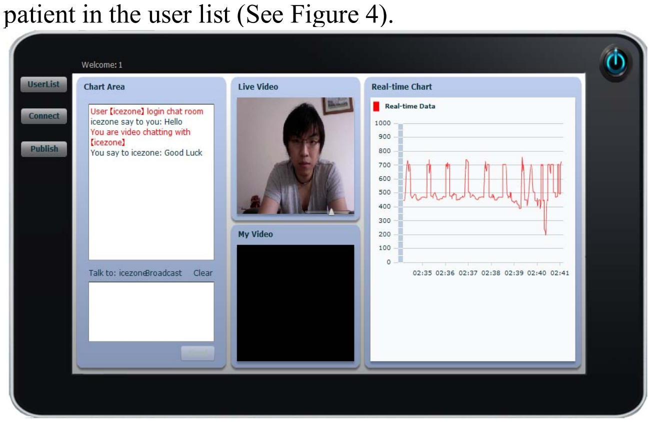

Figure 4. Remote Monitoring integrate With Web Chat Application.

Additionally, a sensor data reviewing application is implemented for the remote monitoring system. By clicking the review button on the main user interface, a new window is popped up and the caregiver is able to define some parameters for reviewing the sensor data, i.e. can select patient profile; define duration for data review; set data priority, choose the type of the sensors readings. Once the caregiver sets up all these options, he can get the sensor data review diagram shown in Figure 5. The graph shows the recorded sensor readings from XML files for the selected patient. It supports zooming and scrolling functions so that a consultant can easily scan the graph, zoom in on any interesting area and and infer the medical analysis.

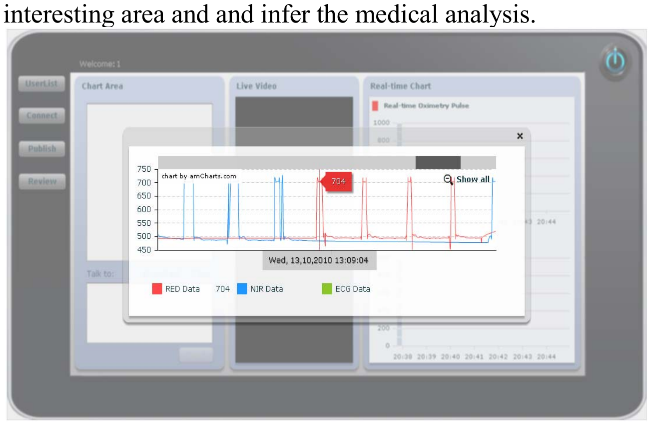

Figure 5. Remote Monitoring integrate With Data Reviewing Application.

By using the remote monitoring system, a medical professional can monitor biological signals remotely through their web browser. Since the data is transmitted in real-time, the physician is able to act on real-time information, rather than on pre-recorded data. The system furthermore allows the medical professional to direct the patient to perform certain diagnostic actions, and see the associated vital sign readings. The video link is two-way, and this is important as it allows the patient to be a full active participant in the consultation. As internet access becomes more readily available at all places and at all times, this application becomes a very convenient and effective tool for supporting remote healthcare services, optimizing the time and convenience for both medical professional and patient.

D. *Healthcare Reasoning System*

The Healthcare Reasoning System is designed to perform three main reasoning tasks: (i) continuous contextualization of the physical state of a person, (ii) prediction of possibly risky situations and (iii) notification of possible emergency situations.

There are many important issues of security, ethics, reliability, integrity, and responsibility associates with such a Healthcare Reasoning System. Our approach is to develop the reasoning aspect of the CARA system in an incremental fashion, and to do so in a way that involves the healthcare professionals, and also in a way that is as transparent as possible to the healthcare professionals.

The Remote Monitoring application of CARA plays an essential role in this. It provides the healthcare professional with the ability to record, replay, and review the patient sensor readings that are the core of the CARA system. In addition it allows them to annotate the signals to indicate events that indicate at risk situations. This allows the CARA system to accumulate expert analysis of the patient sensor readings, thereby providing a basis for actual rues to apply when the healthcare professional is not present and the CARA system is being used in autonomous monitoring mode.

This transparent, incremental approach to the development of the Healthcare Reasoning System using the Remote Monitoring application and involving the healthcare professional is an important and novel aspect of the CARA system.

V. NON-FUNCTIONAL REQUIREMENTS

Several non-functional properties (also called qualityproperties) are taken into account in the design of the CARA system.

A. *Standardized Communication*

An important part of any type of pervasive application is how to build up a standardized communication between tiers or layers of the application so that data can be pushed around. The extensible Markup Language (XML)-based protocols provide a means to develop applications and services that can solve the problem. XML provides the facility to define tags and the structural relationship between them. As a result, developers can create their own customized format in order to define, share, and validate information between computing systems and applications. Since XML has a clearly defined set of standards, people on Team A can easily understand and work with information from Team B. Overall, XML is well designed for data transfer and sharing. We have built a standardized communication protocol for CARA system by adopting XML.

B. *Physical Performance*

Experiments were conducted to test the CARA system's physical performance. The first experiment is to evaluate signal quality between the WMD and a PC at different distances. We fixed the location of the PC and tested wireless communication link quality at distances ranging from 1 to 15m from the WMD. We found that the closer WMD offered better transmission quality (see Table 1). The signal to noise ratio (SNR) value was affected by some obstructions such as doors or movement of the subject.

TABLE I. SNR VALUE OF THE WMD.

WMD	**Distance**		
	1m	***7m***	***15m***
SNR(dB)	11	20	33

The second experiment is to evaluate the impact of the potential delay of the network. We tested our remote monitoring system through localhost, intranet and internet respectively. The results of data transmission delay in milliseconds is shown in Figure 6. The delay caused by internet bandwidth is unavoidable under the current approach. However, this delay is not significant enough to affect the operation of this system.

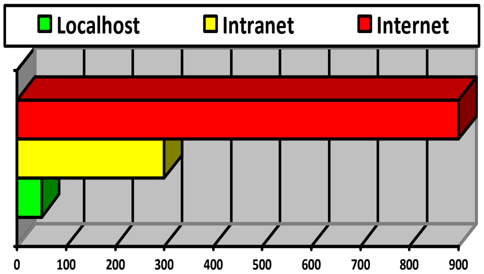

Figure 6. Data Transmission Delay (ms).

C. *Security & Privacy*

Security and privacy issues are taken into account in the CARA system as well. Password control allows only authorized users to login to the CARA system. Authority management is integrated into the system to achieve privacy control, which means that different users can access different functions of the system according to their authorities. For example, the medical consultant can view the patient profile while others cannot. Further work will provide more precise control of various security functions in the CARA system.

VI. CONCLUSIONS

The CARA e-Healthcare system presented here provides a technical solution for soliciting expert feedback on data being streamed from at risk patients when that expert is not around. This system can continuously measure physiological signals and either process the data locally at a basestation or stream the data to a remote location in real-time. A design goal of ubiquitous access means that all communications are performed using recent web technologies. This minimizes issues with firewalls and enables access and analysis on most internet-connected PCs. The caregiver remote monitoring application of CARA is presented as the main implementation example. The only tool required for this application is a web browser with the commonly-available Adobe Flash plug-in installed. Thus remote monitoring, independent of geographic location, is possible form any PC or appropriate smartphone. The CARA system supports the annotation by the healthcare professional of the recorded monitored multi-mode patient sensor data. A novel aspect of CARA is the use of this expert analysis as the basis for the transparent, incremental development of the Healthcare Reasoning System.

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