Non-intrusive Movement Detection in CARA Pervasive Healthcare Application

Bingchuan Yuan
Department of Computer Science
University College Cork
Cork, Ireland

John Herbert
Department of Computer Science
University College Cork
Cork, Ireland

***Abstract*—Pervasive healthcare promises to support the desire of many elderly for independent living and at-home care. This paper presents the CARA (Context Aware Real-time Assistant) system whose design goal is to provide a pervasive real-time intelligent at-home healthcare solution. While this is the goal it is recognized that current practice and current user requirements of both the subject (such as an elderly person) and caregiver (such as a medical consultant) may differ from our ultimate goal. Recognizing this, we have built a solution that supports scenarios of use of CARA other than as a fully automatic pervasive healthcare solution. In this paper we describe a scenario where the full wireless medical BAN (body area network) is used remotely under supervision, and supplementary continuous monitoring of the patient is done in a non-intrusive way via a movement sensor. This movement monitoring is integrated with the CARA system and can make use of CARA's intelligent analysis as well as its recording and playback facilities. While this scenario does not use the full capabilities of the CARA system, it provides a less disruptive introduction to the technology for an elderly person, and leads easily to incremental further incorporation of the technology. The full CARA system has sensors to continuously measure physiological signals, and it can either store the data on a server or stream the data to a remote location in real-time. Implemented as a rich internet application, the only tool required of a remote caregiver is a web browser with the commonly-available Adobe Flash plug-in. Thus the CARA system can be accessed on any internet-connected PC or appropriate smart device. The results of experiments are presented that illustrate the effectiveness of the system in analyzing a patient's movement, and its performance over the internet.**

Keywords- Pervasive Healthcare, Data Review, Remote Monitoring, Movement Monitoring, Rich Internet Application

I. Introduction

The healthcare system has become a national challenge with a rapidly growing aging population and rising expenditure. According to the U.S. Census Bureau[1], the number of people over the age of 65 is expected to hit 70 million by 2030, having doubled since 2000. Healthcare expenditures in the United States were projected to rise to 15.9% of the GDP ($2.6 trillion) by 2010. This challenge calls for a major shift of healthcare from a traditional clinical setting to a patient/home-centered setting, which can reduce healthcare expenses through more efficient use of clinical resources, earlier detection of medical conditions and proactive management of wellness.

One proposed solution to the current crisis is pervasive healthcare[2]. The wide scale deployment of wireless networks will improve communication among patients, physicians, and other healthcare workers as well as enabling the delivery of accurate medical information anytime anywhere, thereby reducing errors and improving access. At the same time, advances in wireless technologies, such as intelligent mobile devices and wearable networks, have made possible a wide range of efficient and powerful medical applications. Pervasive healthcare has the potential to reduce long-term costs and improve quality of service.

Our solution is based on the CARA pervasive healthcare architecture. The architecture supports the various scenarios of use that will be discussed. The main components of the CARA system are:

1. Wearable Wireless Sensors.

A key component of the system is a BAN (Body Area Network, i.e. a portable electronic device capable of monitoring and communicating patient vital signs), and this includes medical sensors such as the ECG, SpO2 meter, and temperature sensor. The BAN plays a central role in health monitoring and in the emergency detection functionality of the system.

2. Non-intrusive Movement Sensor.

A smartphone with a gyroscope and accelerometer is used as a non-intrusive alternative to the BAN for movement monitoring which can provide valuable information regarding an individual's degree of functional ability and general level of daily living activities.

3. Remote Monitoring System.

This is responsible for remotely controlling the BAN and continuously measuring physiological signals of the elderly through the BAN and internet connection. A web camera is integrated to this application that may be used for monitoring and for interaction between the elderly and the caregiver. Furthermore, real-time data obtained from the BAN are recorded on the server for further reviewing and analyzing.

4. Data & Video Review System.

This is designed for the medical consultant or caregiver to review the data previously collected from the elderly in case s/he might be not available for real-time monitoring. This application not only can present the recorded data in graphic chart but also allows the consultant to view the recorded video of the elderly along with real-time sensor data.

5. Healthcare Reasoning System.

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

II. INCREMENTAL USE OF CARA

The CARA system can be used in different ways, varying from fully automatic real-time at-home monitoring of patient vital signs resulting in automated response, to use as a non-automatic assistant for remote real-time consultation by a specialist. While the fully automated system is the ultimate goal, it is recognized this may be too disruptive initially for both patient and caregiver. Healthcare is about more than just immediate application of the most advanced technology. Recognizing this, we have built a solution that focuses on an incremental introduction of CARA as a pervasive healthcare solution. This solution supports a scenario where the wireless BAN is used under supervision (using a two-way video link) during a real-time interactive session with a remote healthcare specialist. This use of CARA is over a short interval of time and is fully supervised with guidance for the patient in the wearing of the BAN and the use of the interactive system. It makes effective use of time for both the specialist and remote patient, and furthermore a facility in CARA to record both video and associated sensor data streams allows the session information to persist.

This restricted use of the CARA system is also important from a number of viewpoints. An inherent problem with all wearable wireless small sensors is noise of various kinds, and this results in data errors. The real-time visual monitoring along with the sensor recordings allows the consultant to disambiguate erroneous readings from significant readings. Furthermore, it avoids the medical, legal and social issues associated with introducing new models of healthcare, and instead is the basis for an incremental approach. This use of the system provides an immediately practicable solution that respects current healthcare practice and the experience of both patient and caregiver, and leads to incremental incorporation of the technology.

While this use of the CARA system is useful, there may also be a need to continuously monitor a patient during normal daily activities. While ultimately this would be done be the wearing of a BAN, a less disruptive initial scenario is the monitoring of patient movement using the sensors available in a commercial smartphone. This is more immediately acceptable, and, by integration with the CARA system, it can make use of the sophisticated analysis and data management capabilities of that system.

III. RELATED WORK

An early method of remote monitoring of physiological signal involved analogue transmission over telephone lines[3], [4], [5], and [6]. Although these systems allow for real-time monitoring, they are constrained by poor bandwidth to a limited number of channels, and suffer from signal degradation due to noise. While Pervasive computing technologies have seen significant advances in the last few years. This has resulted in design and development of sensors, wearable technologies, smart places and homes, and wireless and mobile networks.

Sweta et al. [7] present an architectural framework of a system utilizing mobile technologies to enable continuous, wireless, electrocardiogram (ECG) monitoring of cardiac patients. The proposed system has the potential to improve patients' quality of life by allowing them to move around freely while undergoing continuous heart monitoring and to reduce healthcare costs associated with prolonged hospitalization, treatment and monitoring.

Capua et al. [8] present an original ECG measurement system based on web-service-oriented architecture to monitor the heart health 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.

IV. CARA SYSTEM OVERVIEW

Advancements in internet technology have made possible innovative methods for the delivery of healthcare. Universal access and a networking infrastructure that can facilitate efficient and 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’s vital signs are monitored by different kinds of sensors within a wireless BAN, and are amplified and converted to digital signals. All measurement data gathered by the base-station are then transferred to a gateway (often a PC or a smart phone). The communications links used between the BAN and the personal server will vary according to circumstances.

A real-time classification system for the types of human movement associated with the data acquired from 3-axis accelerometer and gyroscope sensors has been implemented on the gateway. It distinguishes between periods of activity and rest, recognizes the postural orientation of the wearer, detects events such as sitting/lying and falls. Monitoring of different movements and postures involved in the daily routine of older persons who are living alone may help to pave the way for identifying persons who have fallen or are at risk of falling. Such ability may also allow a better assessment of activities of daily living and the effects of numerous medical conditions and treatments.

The gateway connects over the internet to the CARA server which provides sensor data services. An Adobe Flash application running in the gateway publishes real-time sensor data along with live video streams to the CARA server. On the server side, data derived from the sensor data is stored in an implementation independent generic format (i.e. XML), and also kept 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 reactive decision-making on data alerts. 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 record the session, and the system provides the facility to review the session by replaying from the server the recorded readings and synchronized video. The consultants can thus analyze the session and issue a clinical report containing their findings.

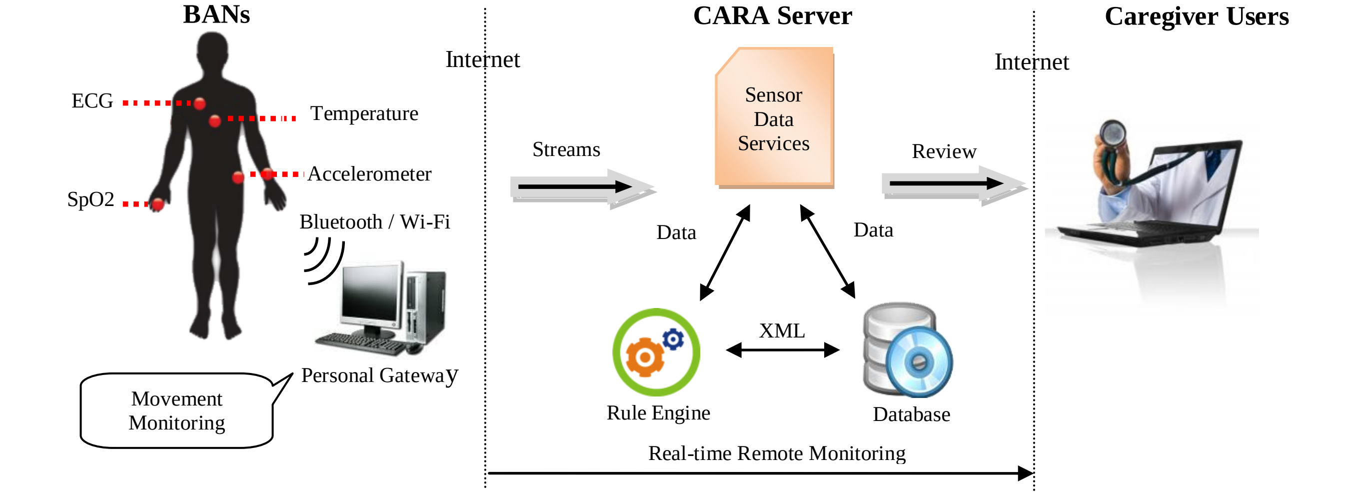

Figure 1. CARA system architecture

V. CARA System Implementation

The current CARA system prototype provides remote physiological signal monitoring using a medical BAN with on-demand video recording services, along with a data and video review functionality to assist diagnosis. The remote monitoring is able to provide continuous real-time physiological signal monitoring over the internet, and it is also able to send alarms when an emergency is detected. The on-demand video monitoring can be used to provide a live two-way video link supporting a fully interactive session between caregiver and patient. Additional movement sensors in a smartphone provide additional non-intrusive monitoring capabilities and these sensor readings are also integrated into the CARA system. All the sensor readings and video records are stored in the database on the CARA server so that the caregiver can review the data anywhere anytime.

A. *Hardware Devices*

The wireless monitoring devices which are the basis of the body sensor network are developed by the Tyndall Institute of University College Cork. The sensor platform is a generic 25mm×25mm module that has been deployed in applications ranging from medical measurement to agriculture. Table I shows the sensors we use. The base-station module comprises an Atmel AVR Atmega 128 micro-controller and a Nordic RF2401 Transceiver. It not only automatically receives the incoming physiological signals from the wireless sensors using synchronization messages, but also transfers the physiological data through a USB connection to the personal gateway. A web camera can be attached to the client when the live video monitoring is required.

TABLE I. SENSOR TYPES AND THEIR SENDING RATES

Sensor type	Sending rate(Bytes/Sec)
Blood oxygen	200
ECG	500
Temperature	100

B. *Software Design*

The CARA system employs a multi-layered software infrastructure based on the features and functions at each of the network tiers. The overall software architecture is shown in Figure 2.

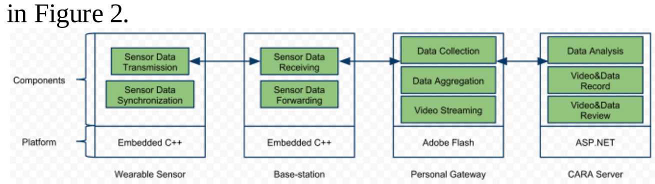

Figure 2. Software Architecture

We use the Embedded C++ programming language to implement the physiological data sensing at the wearable sensors and the data transmission between the mobile wearable sensors and the base-stations. The base-station is also developed in Embedded C++, and this software acts as the middle-ware of the CARA system. It receives sensor data from wireless wearable sensors and forwards them to the personal gateway. We use the windows operation system and Adobe Flex builder to develop the software application for the healthcare client. The client running on the personal gateway is able to collect the sensor data and transfer them to the CARA server in real-time. The CARA server is developed and deployed under the ASP.NET environment on the windows operating system. A built-in database and windows workflow rule engine provide the basis of the data management system on the server which provides data services for the users. Data services include data analysis, real-time remote monitoring and data review functions. Details will be discussed in the follow section.

VI. LOW-DISTURBANCE SCENARIOS AND THEIR IMPLEMANTION IN CARA

As outlined above, a number of scenarios are supported by CARA, and these allow the incremental use of the system and thereby encourage the adoption of the technology.

A. Real-time Remote At-home Monitoring

This scenario involves real-time at-home monitoring under remote supervision by a caregiver. Real-time sensor data and video streams are generated by CARA and sent to a remote caregiver, who might be any suitable healthcare worker, specialist or non-specialist. It involves use of a two-way video link whereby the patient and remote caregiver have direct views of each other. This is an important part of making this scenario low-disturbance and non-stressful, and thereby gaining acceptance for the technology.

The Remote Monitoring System is designed as a web application using RIA (Rich Internet Applications) technologies. In traditional web applications, there is a limit to the interactivity that can be added to a single page. This often leads to delays, during which time users may get tired of waiting and doctors may waste valuable consulting time. With RIA 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. This allows the real time user interaction which satisfies the essential requirement of our system. Adobe Flex is one of the latest trends 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 therefore the client application is implemented using Adobe Flex Builder and Microsoft Visual Studio tools.

To achieve real-time remote video monitoring, the Flash Media Server (FMS) has been built into the CARA server. To launch the application, the user must first log into the web application hosted on the server by providing a correct user name and password. Upon successful login, the main user interface is presented and the user is added into the UserList which is a shared object stored in FMS. By clicking the user list button, the list of all online users currently available on the server will pop up. The communication between the patient and medical consultant can be established by simply selecting a user name on the list and sending messages to each other. This works just like normal messenger tools which also provide live video chat function. If the remote monitoring is required, the caregiver can send a live video request to the patient client, and once the request is accepted, the remote monitoring connection is built up.

Once the wireless wearable devices are set up properly, the application starts receiving data from sensors through wireless communication. In the meantime, the sensor data is transmitted to the CARA server through Action Message Format (AMF) [9] protocol. The sensor data will also be published along with the video stream on the FMS as the metadata. Continuous monitoring is carried out by the caregiver remotely in real-time while the elderly is wearing the wireless monitoring sensors (See Figure 3).

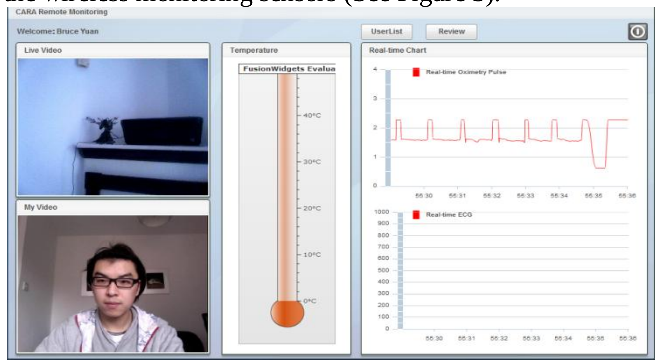

Figure 3. Remote Monitoring Integrate With Live Video Application.

B. Remote Healthcare Data Review

An important use of CARA for the caregiver is the ability to record and review the real-time monitoring session with the patient. It is very convenient for the caregiver to record a monitoring session and then review at any later time both the video stream and associated real-time vital sign data. This plays a part in encouraging use of the CARA system, and is an incremental stage that leads on to the automated use of the system, where long-term at-home real-time vital-sign data may be reviewed by health professionals.

The Data Review System supporting this scenario includes the sensor data review and video replay applications. The data review application allows the caregiver to analyze the full context of sensor readings in order to distinguish critical from non-critical situations. Clicking the review button on the main user interface brings up the data review interface and the caretaker is able to define parameters for reviewing the sensor data, for example: selecting patient profile; defining duration of data reviewing; setting data priority; choosing types of sensors. Once the caretaker sets up all these options, they can get the sensor data review chart shown in Figure 4. It shows the recorded sensor readings from the sensor database for the selected patient or a certain time period. The chart is implemented in Flash by using the amCharts API. It supports zooming and scrolling functions so that users can adjust the graph easily and analyze the data. A playback function is also integrated into the chart which enables the user to play the sensor data graph in any speed.

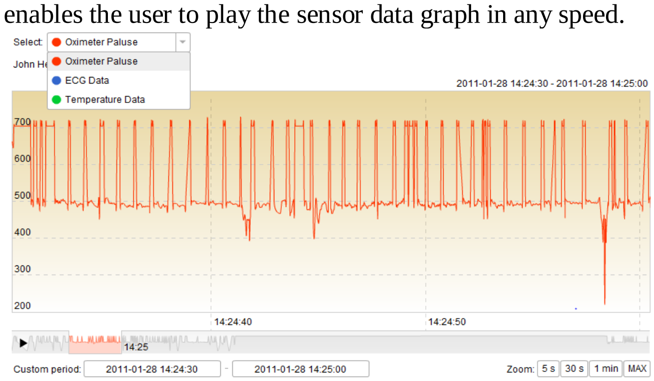

Figure 4. Sensor Data Review Chart

The video replay application is designed for the caregiver to review the recorded patient's live video along with the associated real-time sensor data. This function is developed base on the real-time remote monitoring system. Whenever the patient's live video stream is published on FMS, it is also recorded as a flash video file on the server. To distinguish the video file and to synchronize with the sensor data, several correlations of the video must be recorded into the database as well (e.g. video start time, end time, patient's information). To launch the video replay application, the caregiver needs to select a patient on the data review interface. Then all recorded video related to the patient will be listed on the screen with start and end timestamps. If the video record is not empty, the caregiver is able to replay any of them simply by clicking on the listed item. The system searches the sensor database by the timestamps and plays the video with selected sensor data.

An added functionality of the Data Review System is the ability to annotate to BAN data streams to highlight readings and situations that demand attention. This will allow a caregiver to add their expertise to the system and in this way allow the Healthcare Reasoning System to be improved and refined as more data is added and reviewed.

C. *Automated Movement Monitoring*

This scenario is where the system is analyzing the real-time vital signs and applying rules that identify critical patient conditions. In the more advanced use of the CARA system this will involve analysis of the real-time vital signs when the patient is wearing the medical BAN continuously. For the low-disturbance scenario considered here, rather than wearing the BAN the patient just has to carry a smartphone, and the CARA components that implement this scenario are the Movement Monitoring System and the Healthcare Reasoning System.

The classification algorithm we used for movement monitoring is based on the previous study [10]. We are able to detect postural orientation and falls of the patient by applying the algorithm.

Postural orientation refers to the relative tilt of the body in space. In our application, we have aimed to provide a distinction between the upright postures of sitting and standing, as well as the various sub postures associated with lying. When determining postural orientation, only the gyroscope signal is used because we are dealing with static degrees where tilt is measured. The basic technique employed to perform such classifications relies on evaluating the user's tilt angle. If the patient's tilt angle is 0 to 60◦, it is classified as *upright*, whereas values of 60 to 120 ◦ indicate a *lying* posture; any greater a tilt angle and the user is classified as *inverted*. Mathie [10] determined that a tilt angle between 20 and 60 ◦ is definitely *sitting*, and angles of 0 to 20 ◦ may be either *sitting* or *standing*, depending on various other parameters. Thus, in our scheme, sitting and standing may sometimes be incorrectly classified.

Falls are detected if at least two consecutive peaks in the signal magnitude vector (SVM) above a defined threshold are recorded. SVM [defined in (1)] essentially provides a measure of the degree of movement intensity, as derived from the accelerometer output signal. The threshold was determined by considering accelerations in SVM and in the x, y, and z axes, whereas falls and stumbles were simulated. When such a fall event occurs, a classification of possible fall is assigned to the current time period, and the CARA server will be notified of a potential safety threat. The server will receive the fall event data together with the complete signal for 30 s following the event, via transmission to the medical consultant.

$$SVM = \sqrt{x_i^2 + y_i^2 + z_i^2} \qquad (1)$$

The Healthcare Reasoning System provides a general rule engine that can be tailored with different rules for different situations. It also executes in real-time and offers immediate notification of critical conditions. Some critical conditions may only be identified from correlating different sensor readings and trends in sensor readings accumulated over time.

The Healthcare Reasoning System is capable of performing three main reasoning tasks: (i) continuous contextualization of the physical state of a person, (ii) prediction of possibly risky situations and (iii) notification of emergency situations indicating a health risk. The contextualization involves the processing of raw data coming from sensors by the context management services, producing higher-level information. After this, the rule engine identifies the current state of the patient following a triage-style classification as (normal, alert or emergency). This can be achieved in two steps: in the first step, the standard common rules are applied; in the second step, patient and condition-specific rules are applied. For example, if the current inputs (physiological values) are atypical (e.g., do not occur frequently) for the patient, an alert output can be consolidated as an emergency. The generated data is stored for additional analysis, and to assist any related reasoning-based systems.

VII. SYSTEM EVALUATION

A. *Precision of Movement Monitoring System*

An evaluation of the test results involved comparing the subject's actual movements with the movements classified by the system. If the classified movement actually occurred during the appropriate time interval, then this outcome was recorded as a correct classification; if a particular movement produced an unexpected classification, then this outcome was considered an incorrect classification. In this way, the accuracy of the system in correctly classifying the movements of the tests was measured (see Table II).

TABLE II. RESULTS OF MOVEMENT EXPERIMENTS

Movement	Task	Tests	Correct	Accuracy (%)
Postural Orientation	Stand→Sit	40	39	97.5
	Sit→Stand	40	40	100
	Lying→Sit	25	23	92
	Sit→Lying	25	25	100
Fall	Fall (active)	20	20	100
	Fall (inactive)	20	20	100

B. *Physical Performance*

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

TABLE III. 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, and the results indicating data transmission delay in milliseconds are shown in Figure 5. The delay caused by internet latency is unavoidable under the current approach. However, this delay does not significantly affect the working of this system.

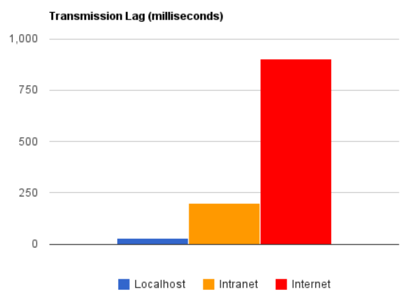

Figure 5. Data Transmission Lag

C. *Security & Privacy*

Security and privacy issues are taken into account in the CARA system as well. Password control allows only authorized user to log in to the CARA system. Authority management is integrated into the system to achieve the privacy control, which means 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.

VIII. CONCLUSIONS

The CARA pervasive healthcare system presented here provides an advanced technical solution for automated at-home healthcare. It is recognized, however, such a change from current practice may be unacceptable, and incremental introduction of the technology may be the best path to successful use of the technology. Following this approach, the system supports scenarios where the wireless BAN is used under remote supervision for a real-time interactive monitoring session with a caregiver, and a scenario where the BAN is not worn and continuous automated monitoring is just based on sensors in the smartphone carried by the patient. While not using the full capabilities of CARA, these scenarios provide a non-stressful introduction of the technology, and gain acceptance for more advanced scenarios such as non-interactive, at-home automated patient monitoring using the BAN.

Important aspects of the CARA system 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, where the annotation of significant parts of the multi-modal monitored signals by the medical professional provides the basis for the improving automated intelligent analysis. A design goal of ubiquitous access has resulted in a web-based implementation that provides access and analysis capability on any internet-connected PC or appropriate smart device. The paper has provided an overview of the CARA system and scenarios of its use, and presented results of experiments using the system.

ACKNOWLEDGMENT

This project is funded by Science Foundation Ireland. We are also grateful to University College Cork and the MISL Research Group.

REFERENCES

[1] U. C. Bureau, "International Database. Accessed via Internet:http://www.census.gov/ipc/www/idb/," November 2008.

[2] U. Varshney, "Pervasive healthcare," *Computer*, vol. 36, pp. 138-140, 2003.

[3] O. P. F. Vaz, "A telemedicine application for EEG signal transmission," A. M. d. Silva, Ed.: Annual International Conference of the IEEE. Engineering in Medicine and Biology Society, 1991, pp. 466–467.

[4] R. M. Gardiner, "Eight channel data set for clinical EEG transmission over dial-up telephone network," D. R. Bennet, Ed.: IEEE Transactions on Biomedical Engineering, 1994.

[5] C. D. Ray, "Experiences with telemetry of biomedical data by telephone, cable and satellite: Domestic and international," R. G. Bickford, Ed.: Medical Electronics and Biological Engineering, 1995.

[6] M. L. Bykhovskii, "Transmission of medical information through telephone lines," vol. 2, E. M. Krishchyan, Ed.: Biomedical Engineering, 1998, pp. 307-313.

[7] S. Sneha, "A wireless ECG monitoring system for pervasive healthcare," vol. 3, U. Varshney, Ed.: International Journal of Electronic Healthcare, 2007, pp. 32-50.

[8] C. De Capua, "A Smart ECG Measurement System Based on Web-Service-Oriented Architecture for Telemedicine Applications," vol. 59, A. Meduri, Ed.: Instrumentation and Measurement, IEEE Transactions, 2010, pp. 2530-2538.

[9] A. S. Inc, "AMF3 Specification. Category: ActionScript Serialization," 2006.

[10] M. J. Mathie, A. C. F. Coster,B.G.Celler, and N. H. Lovell, "Classification of basic daily movements using a triaxial accelerometer," *Med. Biol. Eng. Comput.*, vol. 42, pp. 670–687, 2004.