R&D CHALLENGES IN DEVELOPING AN AMBIENT INTELLIGENCE E-HEALTH PLATFORM

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Abstract: Several R&D issues need to be resolved in tomorrow's eHealth care platforms to support personal health management services as well as mobility of patients and health professionals, by seamlessly integrating these services with smart surroundings that use self-configuring devices, intelligent agent technology and tools for ambient awareness and decision support. Such services, when interoperating with a life-long electronic health record of a citizen, can become the cornerstone for supporting continuity of care and cost effective health care for all. This paper discusses the architectural considerations and the R&D issues addressed in the design, development and implementation of the Ambient Intelligent platform for Cardiology (AmICa), a modular and flexible ambient intelligent eHealth platform for remote multiparametric monitoring of patients, able to be adapted to different care provision modes and daily life situations.

Introduction

Recent advances in Information and Communications Technology (ICT) enable the acquisition, transmission and interpretation of different bio-signals from fixed or mobile locations, at an acceptable cost, even simultaneously when required by a clinical scenario. This capability can support better prevention and well being and provide more valuable and prompt diagnostic tools in various application domains, ranging from home care to emergency care, or situations in which a second or a specialist opinion is required before taking a clinical decision.

Important trends in healthcare include citizen mobility and the consequent move towards shared or integrated care in which the single doctor-patient relationship has changed to one in which an individual's healthcare is the responsibility of a team of professionals in a geographically extended healthcare system. In this new scenario, the possibility of consulting and collecting clinical information from different points is becoming a common need for citizens and physicians. Moreover, the increase in the life expectance has produced an older population that may need continuous assistance especially in cases of serious or chronically ill people that wish to live independently. A clear benefit is obtained when high quality of care can be delivered outside the hospital premises allowing people at risk or patients with proved health problems to continue their usual life at their homes and work places. Remotely delivered care for prevention or follow-up situations is becoming increasingly feasible, through sophisticated eHealth services facilitated by intelligent environmental and biomedical sensors, portable monitoring devices, hand-held or wearable technologies, the Internet and wireless broadband communications.

In this perspective, with focus to the provision of high quality of care, assuring life independency, the significant new research challenge is the integration of multiple sensor streams, to extract local and global health-state indicator variables that can be queried and monitored by an unobtrusive system. Using ubiquitous computing, social user interfaces and inexpensive wireless communication technology, intelligent eHealth spaces can be created, accelerating the extensive deployment of sensor technology in tomorrow's eHealth services.

This paper discusses the R&D issues that need to be resolved in order to allow tomorrow's eHealth care platforms to support personal health management services as well as mobility of patients and health professionals, by integrating them with seamlessly accessible ubiquitous intelligent surroundings that use self-configuring devices, agent technology and tools for ambient awareness and decision support. This paper also discusses the architectural considerations and the R&D issues addressed in the design of the Ambient Intelligent platform for Cardiology (AmICa), a modular and flexible ambient intelligent eHealth platform for remote multiparametric monitoring of patients, able to be adapted to different care provision modes and daily life situations.

Materials and Methods

A. Background work

eHealth tools or solutions include products, systems and services that go beyond simply Internet-based applications. They include tools for health authorities and professionals as well as personalized health systems for patients and citizens. Examples include health

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information networks, electronic health records, telemedicine services, personal wearable and portable systems, health portals, and many other information and communication technology-based tools assisting prevention, diagnosis, treatment, health monitoring and lifestyle management. Today, at least four out of five European doctors have an Internet connection, and a quarter of Europeans use the Internet for health information [1].

eHealth services, when combined with organizational changes and the development of new skills, can help to deliver better care for less money within citizen-centred health delivery systems. It thus responds to the major challenges that the health sector – which employs 9% of Europe's workforce – is currently facing. eHealth is today's tool for substantial productivity gains, while providing tomorrow's instrument for restructured, citizen-centred health systems and, at the same time, respecting the diversity of Europe's health care traditions [2].

The eHealth Laboratory of the Institute of Computer Science at FORTH has in the past focused its R&D activities on addressing the issues involved in the design, development, deployment and evaluation of novel eHealth services, designed with adherence to open standards, facilitating professional collaboration across organizational barriers, patient telemonitoring and telemanagement [3, 4]. A main result has been the deployment in the island of Crete and other Greek regions of an eHealth technological platform that integrates several different biomedical devices and takes advantage of hybrid communications through satellite, mobile, wireless or wired network infrastructures to support the delivery of high quality of health care services in the context of a regional health information network. In this infrastructure several other systems, like the Pre-Hospital Health Emergency Information System and the Primary Health Care Center Information System (PHCCIS), seamlessly integrating the same biomedical devices, have been deployed in the same geographical area. All these systems are integrated with the lifelong I-EHR and allow each medical encounter or biomedical data acquisition to be stored in the patient's EHR assuring continuity of care and reducing, at the same time, medical errors [5].

A.1. Biomedical devices

A wide variety of commercial medical devices from several manufacturers have been exploited and integrated in different eHealth services and systems demonstrating their reusability. Each device has been wrapped up as one or more software components that can be downloaded on demand from the Internet and configured in the context of different use cases. The different components were mainly dedicated to: data acquisition, from the medical device, real-time transmission to remote systems, data storage including waveform, demographic information and, when available, signal post-processing with measurements and diagnosis, and data display.

A modular approach had to be applied to assure reusability. Thus, the integration of each device needed the realization of different software components such as a modular/extensible viewer/player able to display/play the stored medical examination taking into account of different parsing techniques depending on the vendor/model of the medical devices and a specific acquisition module for each device with storage capability. This design choice facilitates device and system testing and allows a higher modularity. The device modules currently developed are presented in Figure 1.

Depending on the medical device, its intrinsic capabilities and the clinical scenarios, some pre-processing can be performed at the patient site (i.e. an interpretive electrocardiograph or a hand-held spirometer where the main measurements are evaluated by the device itself). In such case, the device has the capability of locally storing the medical examination and to work according the store & forward paradigm. For such device real-time transmission is not supported and the clinical examination is sent to the repository with a file transfer protocol where can be retrieved by each user securely connected to the platform.

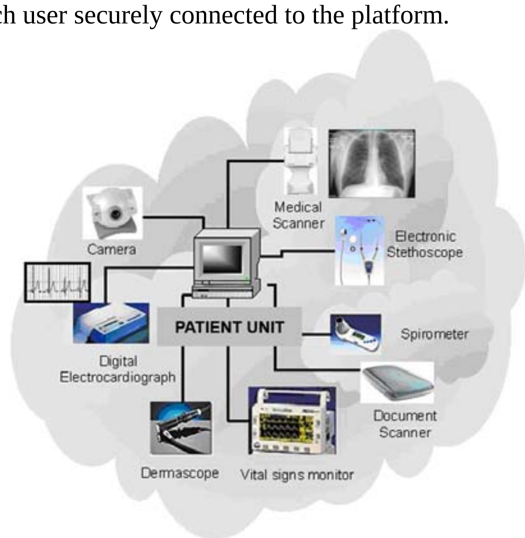

Figure 1: A wide variety of medical devices has been developed as modular components

Devices that support the real-time mode maintain their feature in their integration with the platform. The information (raw or very lightly pre-processed) is transmitted to the remote site through a TCP protocol and real-time transmission (i.e. 12-lead ECG and stethoscope sound simultaneously) can be sustained with a guaranteed bandwidth of 64 Kbps [6].

B. Ambient intelligence eHealth services

Ambient Intelligence is an exciting new concept in information technology, in which people are empowered through a context aware environment that is sensitive, adaptive and responsive to their needs, habits, gestures and emotions. Ambient intelligence merges two important trends *'ubiquitous computing'* and *'social user interfaces'* [7]. It is expected that, by providing an intelligent environment, quality and cost control can be improved and innovative intelligent personal health services can be developed.

The overall objective of our current work has been to define, develop, prototype and validate an ambient intelligence service platform that integrates mobile users into intelligent surroundings and deliver on-demand services and support for ad-hoc collaborative workgroups across geographically distributed organizations talking also advantage of FORTH's past experience in the development of the eHealth technological platform and integration of biomedical devices.

B.1. Scenario of use (cardiology case study)

In the cardiology domain, patients with heart risk may continue their normal life if adequate monitoring of the heart functionality can be performed during their daily activities (prevention). Similarly, patients with proved heart problems may continue their independent living outside the hospitals if again an adequate monitoring of their heart functionality can be performed during their daily activities (follow-up). In both cases, it is possible to reduce hospitalization days, thus reducing the cost for healthcare providers while delivering high quality of care to patients, assuring also life independency. A common, affordable and effective way for heart monitoring is through the recording of at least 3 ECG leads. Such equipment has the main feature to be non-invasive and non-intrusive for the patient, thus increasing patient's acceptance of the device.

A today's typical scenario is described below.

Mr. Nikos is a 55-year-old man living in a district village in the mainland of the island of Crete in Greece. He has chronic cardiac problems and visits once a week his local General Practitioner (GP) for a health check. The GP examines Mr. Nikos and uses the already deployed eHealth services of the Regional Health Information Network (RHIN) of Crete (HYGEIAnet) [8]. The RHIN provides a framework for the integration of a diverse set of heterogeneous and distributed information sources into what appears to be a uniform collection of data and knowledge and support the lifelong I-EHR [9] of the patient.

Let us envisage Mr. Nikos in a scenario of future ambient eHealth services.

Mr. Nikos is monitored and assessed by a distributed care team, his GP and other medical specialists located in remote primary health care centres. The care team identifies that the patient's heart condition must be monitored using "AmICa" (Ambient Intelligence platform for Cardiology), an ambient intelligent system that allows the monitoring of cardiac patients.

Mr. Nikos is given a wearable unit able to collect various vital sings and significant environmental data and transmit them to a base unit, installed at his home. It collects, compresses and packetizes all data acquired by the wearable unit and environmental sensors, and finally transmits them to the AmICa server at the Primary Health Care (PHC) centre. Mr. Nikos' wearable unit, when he is on-the-move, is able to securely transmit the data using the public wireless communication infrastructure.

Mr. Nikos activates the equipment and continues his normal daily activities. The system senses the activation of the patient unit and notifies the GP. The GP, using his certification credentials, enables the automatic upload of the acquired data into the EHR of the patient. He also sets up the monitoring scheme and notifies all the other members of the distributed care team about these actions. Adaptive thresholds are set on the patient heart rate to generate alarms depending on his physically activity. Mr. Nikos' physical activity is evaluated through motion wearable sensors. Such sensors are also applied for an estimation of the energy expenditure [10] in order to warn the patient in case this does not match with the prescribed lifestyle.

The AmICa server performs medical and environmental data fusion and processing using the patient health profile obtained by the lifelong I-EHR. An excessive physical activity can produce in heart risk patients an excessive ST depression that, when detected and correlated to a high physical activity, generates an alarm indicating the patient to stop immediately his action and to initiate a recovery phase where the ST depression needs to be monitored in order to verify its gradual reduction and return to the normal level. Other useful indications are obtained evaluating the patient's Heart Rate Variability (HRV) after a prescribed physical activity program. Regular physical activity, which slows down the aging process, has been shown to raise HRV, presumably by increasing vagal tone [11]; thus, in the long period, after a daily measurement of the physical activity in order to verify the correct execution of the program by the patient, an evaluation of the improvement in the patient's HRV is performed.

The distributed care team is able to alter at any time the monitoring scheme and the rules that force the engagement of the system's reactions depending on Mr. Nikos' health status.

C. R&D challenges for ambient eHealth services

In a hectic working environment, where many tasks are carried out in parallel, where clinicians move from one setting to another, and where collaborative settings constantly emerge, it is important that clinical computer applications have knowledge about the user's working context and are able to adapt to this context. ***"Support for context-awareness"*** should be part of the basic infrastructure, rather than something implemented by each clinical application. Mechanisms for cooperation built into the very basic infrastructure of the healthcare system are currently used for allowing collaboration among physicians and patients, but the new challenge is to facilitate these services through smart context aware environments [12].

"Knowledge acquisition & representation" is the milestone for the set-up of context awareness mechanisms based on patient health profiles, patient

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behaviour and reaction to activities. Possibility of continuous data acquisition from anywhere in a non-intrusive way may allow the construction of a solid knowledge base enabling the understanding of physiological and pathological parameters in correspondence of different activity patterns and personalized for different patients. Such knowledge representation is the base for the application of knowledge discovery algorithms that can promote non-evidence-based medicine besides evidence-based medicine. A strictly connected challenge is ***"data fusion of multisensor data"*** in order to take advantage of an extended knowledge base for an optimal evaluation of patient's clinical status.

A major R&D challenge is the ***"integration with the lifelong I-EHR"*** in order to create an active electronic health record able to react, using the knowledge extraction and discovery features, to the acquired data, helping the medical personnel in following the specific guidelines and leading the patient to the correct wellness pathways. This integration can provide the best support for continuity of care and, widening the patient's available clinical information, give the GPs all the elements for a correct diagnosis reducing clinical errors and improving the quality of care. A correct setting of the personal health profile needs to be based on the overall clinical information of the patient that only a complete lifelong I-EHR can provide.

Today, security issues are described as concepts of communications and applications with their related services, allowing one to focus on the relevant area of interest. Regarding the general security model distinguishing between communication security and application security, strong authentication is needed for security services involved in both concepts. Services specific to communication security are identification, authentication, integrity and certification, while security services specific to application security are authorization, access control, data quality and audit. In this new environment where the patient can be continuously monitored at any time from any where, issues like security and privacy become even more pressing than in the past. Thus, ***"trust, security and privacy"*** also becomes a major challenge.

C.1. Ambient eHealth services requirements

Ambient & collaborative eHealth services reside in a complex, continuously growing world, where numerous devices, services, and applications cooperate with users to support scenarios, like the previously mentioned one. In these heterogeneous contexts, flexibility and adaptability to different use case scenarios are required for these services.

The wide variety of potential users and terminal devices suggests adoption of user friendly and natural, interfaces for fast and simple user interaction. To this end, multimodal user interfaces must be supported to extent the users' basis to the widest possible spectrum, by satisfying their diverse needs, providing high accessibility.

In addition, scalability constitutes an equally important requirement with relevant impact on overall system performance. Performance should be scaled proportionally to the number of resources used to give the necessary quality of service, in relation to the number of end-users.

Easy portability or even better wearability of medical devices is another significant requirement trying to improve patient's comfort with the use of non-intrusive devices with low power consumption and high autonomy. Seamless integration of such devices in the ambient eHealth services is also required. To this intent, interoperability between diverse devices and software elements is required as well. Use of plug&play medical devices, conformed to well established interoperability standards, assures seamless integration and platform flexibility. Unfortunately plug&play interoperability is not yet a reality, but it could represent the future challenge for manufacturers.

C.2. Ambient intelligence platform for cardiology (AmICa)

AmICa is a context sensitive service platform offering ambient eHealth services across heterogeneous networks as well as supporting mobility among users by integrating them with seamlessly accessible ubiquitous intelligent medical devices and tools for ambient awareness and decision support. It allows a distributed care team to continuously monitor the patient's health status with the aid of an intelligent integrated cardiology and environmental analysis system.

In the AmICa platform, R&D challenges like context-awareness as part of the basic infrastructure, integration of eHealth services with the lifelong I-EHR and trust, security and privacy mechanisms are specifically addressed by the selected AmICa architecture.

The trusted computing base of the AmICa platform includes computer security mechanisms to enforce user authentication and access control, communications security mechanisms to restrict access to information in transit across a network, statistical security mechanisms to ensure that records used in research and audit do not possess sufficient residual information for patients to be identified and availability mechanisms, such as backup procedures, to ensure that records are not accidentally deleted.

The main functionalities of the AmICa platform are: a) *Monitor* the patient and automatically store the acquired data into a centrally managed patient's electronic health care record. The GP can change the monitoring scheme and configure it to meet the patient's needs; b) *Analyze* the acquired data using special analysis methods, and *interpret* these measurements for taking *intelligent actions* depending on the patient's heart conditions correlated to the specific activity pattern of the patient himself; c) *Notify* the users, patients and medical personnel, using a dedicated notification system, for all the actions that need to take place, with the capability of scaling its response depending on the observations (i.e. some users or all of them can be notified); d) *Log* all the actions that took place in the AmICa persistent store.

Results

A. AmICa architecture

The platform consists of a layered architecture: the Ambient Intelligent (AmI) server, the client and the devices. The AmI server is the core of the system, providing the functionality required. It is able to handle all application specific intelligence issues. The design incorporates the existence of various tiers within the server layer. Each one of them represents the specific functionality we want the server to employ.

The server could be physically located either centralized or distributed across health service providers, allowing maximum flexibility during deployment. In more details it contains management structures, application specific and location specific decision support structures, alarm handling, user profiling and other general purpose tasks inherent to the specific functionality of each application scenario. It cooperates with a data repository with large storage capacity, where user information, access privileges, user setup profiles as well as acquired data and alarm situations are stored.

The client layer is responsible for service and device discovery in response to a specific user need. The client layer has many hierarchical structured modules, concerning the ways it interacts with the server and the devices. It employs web services responsible to give access to the medical and environmental data, using the OSGi framework [13].

The device layer includes the various devices interacting with users. This layer allows the ubiquitous user interaction with the system through sensor devices, medical devices, personal device assistants (PDAs) and more.

The system incorporates a close loop procedure where it uses the device layer to collect data and the client layer to transfer the locally acquired data to the server. The ambient intelligence server receives the data and, based on the results of its processing and analysis tasks, decides on the list of actions the system should invoke.

B. AmICa main architectural components

The AmICa framework embeds the following sub-components (see figure 2):

a) Context-awareness component - A central part of the infrastructure that continuously monitors the users' context and gathers information. It can be accessed from clinical applications, or can be setup to notify applications when appropriate.

b) User authentication component - A component that enables proximity-based user authentication.

c) Collaboration component - The framework embeds basic support for collaboration among users. Shared workspaces are incorporated allowing the users to join an activity and conduct real-time sessions.

d) User awareness component - A component that helps clinicians to judge who and how to initiate a collaboration session. It is a central part of the collaboration support and tries to provide clinicians with a peripheral, social awareness on what their colleagues are doing. This component uses information about the activity and context of users.

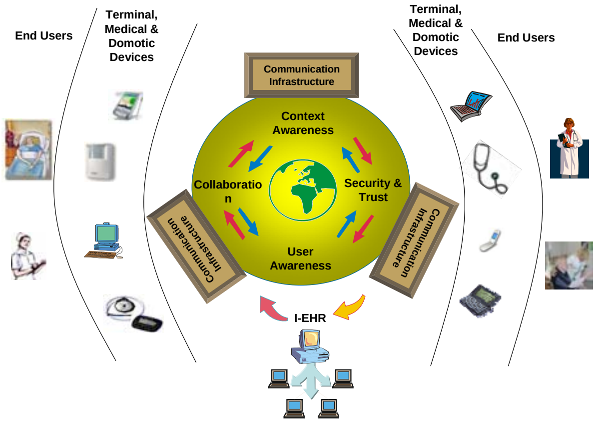

Figure 2: The AmICa architecture

C. AmICa communication infrastructure

The telecommunication infrastructure is a combination of fixed and wireless communication technologies.

The platform is able to perform automatic roaming across heterogeneous networks in order to provide interoperable services.

D. User modelling and context awareness

For any user assisting technology to be useful and not merely irritating, it must have some knowledge of the user to be assisted: it must understand or at least predict what the user will do, when he will do, and, ideally, the reason for his actions. User modelling is a necessary step toward answering some of these questions. Csinger defines user modelling as "…the acquisition or exploitation of explicit, consultable models of either the human users of systems or the computational agents which constitute the systems" [14].

The risk of misleading the user is one that designers should not ignore. Real-world environments are complex, and the information available is likely to be limited and imperfect. Presenting the user with incorrect information can result in a decrease of performance.

More complex than the problem of misdirection is the problem of divided attention. Contemporary theories of attention [15] are based on finite resources of perception and cognition. Simultaneous tasks that require conscious attention compete for a person's limited attentive resources.

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The tasks interfere with one another, and the person's performance suffers on all of the tasks. Interference issues are particularly problematic. Task interference by a support application can be mitigated by reducing its perceptual or cognitive demands. One important technique for reducing interaction complexity is *context awareness*. This is the use of non-explicit user and environmental input, typically acquired through sensors [16]. Context awareness can reduce, or in some cases eliminate, the need for explicit user input for some applications.

We are considering and implementing techniques that utilize auditory events in the environment to provide contextual cues for user interfaces and applications. Such cues enable a context aware application to provide relevant or timely information to the user, change its operating characteristics or take appropriate actions in its physical or virtual environment [17].

Discussion & Conclusions

In this paper we present experiences of our ongoing R&D activities in designing and developing an ambient intelligence eHealth platform.

Our efforts focus on the development of new, innovative ambient intelligence service platforms for automatic, context sensitive offering and contracting of eHealth and mHealth services across heterogeneous networks. The existence of a lifelong integrated electronic heath and novel eHealth services are fundamental to bring the paradigm shift in the healthcare system namely individualized and evidence based medicine.

Initial evaluation experiences indicate that the use of ubiquitous and inexpensive wireless communication technology can create intelligent eHealth spaces, accelerating the extensive deployment of state-of-the-art sensor technology for the delivery of the next generation of eHealth services. Such services, when interoperating with a life-long electronic health record of a citizen, can become the cornerstone for supporting continuity of care and the evolving, novel eHealth services of today for every citizen.

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