

An Architecture for development of Ambient Assisted Living applications: A case study in Diabetes

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Abstract— Advances in sensors, mobile and embedded devices have made possible patient monitoring and provided medical treatments and other assistance in health care. Aging populations will benefit from reduced costs and improved health care through assisted living based on these technologies. In this paper we present a monitoring and control architecture allow control of a patient's disease through mobile and biometric devices. Our architecture is based on an Ambient Assisted Living control that provides different modules organized in a final application embedded in the mobile devices. This application is compounded by aspects like control of measurement, data obtained and representation, generation of suggestions, prevention, and education control. We have explored the architecture by developing a final application and implementing them in a prototype system. Our system shows the feasibility and opportunity of an open approach to ambient assisted living architecture.

Keywords- *ambient assisted living; chronic diseases; mobile monitoring, diabetes, applications to auto-monitoring.*

I. INTRODUCTION

Healthcare represents a particular type of Ambient Assisted Living (AAL). The concept denotes an intelligent environment customized for monitoring and assisting elderly or disabled patients while living at home. The purpose of such a system is to allow the user to have a normal life in a familiar environment. The system is designed for patients not requiring permanent medical surveillance. Studies reveal that such systems will be well received by patients and families.

Our architecture offers significant benefits of the daily activities of patients. This activity must meet specific requirements in order to evaluate the effective functionality of the architecture. The following requirements are very important in our architecture:

a) Flexibility: This architecture is easy to use, the patient needs only use the mobile and biometric devices. The patient must take measurements which are fed into the biometric device and then read by the mobile device. The mobile device captures the vital signs, interprets and then compares them independently with measurement ranges established for the patients' disease. Once the tests are read and interpreted, they are transmitted by the control modules

embedded in the mobile device. All this activity is transparent to the patient.

b) Vital sign measurement and interpretation: With the proposed system, vital signs (such as the glucose level, blood pressure, temperature, and others) can be measured and transmitted via Bluetooth technology between the mobile and biometric devices. If the biometric device doesn't have Bluetooth technology, the patient can load vital sign measurements manually.

c) Activities control: Control of activities includes those the doctor recommends and are detailed in the module generation framework. These activities allow us to adjust future definitions of modules used for patient monitoring.

They are composed of Prevention which works according to a schedule of the patient's activities. The system learns the system itself based on patient behavior during certain activities, thus establishing a relationship between measures, trends and implementation of an activity. The patient is also educated on their condition from the information provided during treated. This added value to the system is not associated with information obtained from the biometric sensor, but instead is a by-product to our architecture.

In *the recommendation*, the system offers the patient options via recommendations presented based on particular activities performed, or by variations in the measurements taken at a given time. The recommendations may include suggestions on a diet to follow, the use a specific medical treatment, and others.

d) Self-control: Self-control or patient-provided information obtained from a patient's history of actions and tendencies, are stored in individual profiles. Here you can view information through graphs and tables by which you can make changes in levels desired from a sensor device (e.g., Glucose Meter, blood pressure, etc.).

e) Privacy: medical and personal data is protected with different levels security based on an individual's role or relationship with the patient (e.g., Health care providers, medical specialists, relatives, etc.).

The system will be evaluated based on the extent to which these technologies help people with independent

living at home or in assisted living facilities, and their willingness to use these technologies in their situation. We start by selecting a group of five patients with diabetes. These patients will use the application for two days and from these results we can determine whether our systems architecture can provide a good solution to those needing living assistance, and do it anywhere and anytime.

In this paper, we first review the existing research by bringing human participation into ambient assisted living systems. Next we present our system architecture.

II. RELATED WORKS

Many assistive systems, both for indoor and outdoor environments, have been developed. Most are focused on a single task such as vital sign monitoring, fall detection, environment customization or to locate a person. Less complex systems are represented by a radio transmitter which acts as an alert beacon when a button is pushed. Limited effectiveness may be expected based on the fact that during a heart attack or a stroke the patient may not be able to push the panic button. Other systems are based on using a public or mobile phone or pager-like device.

We know other research exists in assisted living, however, that research is based on specific developmental technologies and control devices. In this section we will present our project and discuss the difference between us and existing architectures.

At Georgia Tech [1] [2] the Aware Home project created a home environment that monitors its occupants' whereabouts and activities. The services provided by Aware Home range from enhanced social communication like providing a digital portrait of an elderly person to family members, to memory aids that assist users in resuming interrupted activities by using playbacks of video recordings of past events. Next, in [3] there was presenting related research to the aspect of home health monitoring using a Smartphone. We are developing an architecture that allows the use of different mobile devices with different biometric devices. This architecture generates interfaces based on the diseases input as a healthcare control.

At the University of Virginia [4] developed a smart in-home monitoring system to collect data with the use of a suite of low cost, non-intrusive sensors. The information collected is logged and analyzed in an integrated data management system. The system essentially collects information in a passive manner and does not directly interact with the person being monitored. We collect data from each patient through mobile devices when a patient uses the biometric device. This data is stored on a server allowing for patient control, and to provide suggestions for prevention and progression of diseases.

Intel [5] is focused on improving care in clinical environments, advancing personal health technologies for the home, identifying new care models and work practices, and promoting standards and policies that enable innovation and interoperability across the healthcare ecosystem. Some research development by Intel is focused on Technology Research for Independent Living (TRIL), Everyday

Technologies for Alzheimer Care (ETAC) and Aging services.

At the Center for Future Health (CFH) at the University of Rochester [6] the smart medical home prototype consists of infrared sensors, computers, bio-sensors, and video cameras. The key services provided are medical advisory, which provides a real-time conversational interface between the patient and health care expert, as well as motion and activity monitoring, pathogen detection, skin care, and personal health care record for consumer-provider decision support.

The ElderCare [7] platform aims at providing a holistic ICT infrastructure for AAL in any home or residence. It is affordable, unobtrusive, easily deployable, usable, accessible and available. It describes the architecture and components of an AAL-enabling platform, centered around interactive TV (ITV), which combines OSGi middleware, RFID and NFC in order to ease the day to day impact on dependant or semi-dependent elderly people (its main focus), their caretakers and relatives.

Our goal [8] is to provide healthcare monitoring, continuously both at home and beyond. People need to have their health conditions under control not only when they are at home, but everywhere.

III. SYSTEM ARCHITECTURE

The mobile monitoring system integrates heterogeneous devices, some connected directly with the mobile devices through communication technology (Bluetooth) and some without communications technology. Together they inform the healthcare provider about the health status of the patient.

Data is collected, aggregated, pre-processed, stored, and acted upon using a variety of sensors and devices in the architecture. The interaction between the biometric devices, mobile devices and full system architecture, form the nucleus of our patient constant monitoring. By obtaining vital signs and their appropriate interpretation for the generation of medical monitoring applications, all these activities can be done from home and beyond with the patient leading a normal and routine life.

The focus of our research is to create a complete architecture with different services that allow the patient through biometric devices to provide data and information to mobile devices (e.g., Mobile phone, PDA, Internet Tablet or small computer) which not only collects information, but will evaluate trends, provide advice on health and diet or suggestions on prevention of certain aspects of a disease, and does so via a transparent and redundant data link between the patient and his/her personal mobile device. Figure 1 shows the proposed architecture.

On the left, a number of healthcare and monitoring devices are connected to Bluetooth mobile devices. In the center, these biometric devices are linked to a mobile phone to process sensor data, manage AAL applications and ensure redundant connectivity via 3G and WiFi data networks.

Information is transmitted to a central database and advisory system for evaluation and monitoring by the

medical server (right). The following explains each element of the system architecture.

A. Biometric and Mobiles Devices

Mobile devices provide richer interfaces to real-time and historical data. Biometric devices are an important technological support factor for smart environments and ambient assisted applications. Up to now, most applications were based on mobile solutions for biometric devices and solutions providing uniform and reusable applications are still in their infancy. Note that AAL spaces can be populated by many sensor networks (e.g. ZigBee or IEEE 802.15.4 standard, and Bluetooth).

B. Applications and Modules

Mobile devices provide richer interfaces for real-time and historical data. This architecture works as a bridge between the patient and the monitoring modules. It starts when the system boots-up and loads the applications, passing them through the parameters defined in the configuration files. Architecture developed in this paper is illustrated in two specific areas: the first corresponds to the needs of the doctor and the second corresponds to the needs of the patient. The doctor application is installed on their PC; it is allow to control all records of their patients which have been organized by the patient’s profile, including historical controls of their measured data and specifications of their disease (s).

In the patient application, the program is installed on their mobile phone. We have developed the application using the Android Operating System with remote connectivity through MySQL. The patient mobile phone has a screen with a menu that lets them access all functions of the application.

C. Patterns Generation

The system architecture we have developed allows the construction or generation of interactive applications to be embedded in the mobile device (PDA, mobile phone, etc.).

For the creation of these modules and integration of each, and the generation of mobile applications, we have defined and developed a set of patterns called “MobiPattern”. For the definition of any MobiPattern we must consider all representations made as having been generated after performing a measurement.

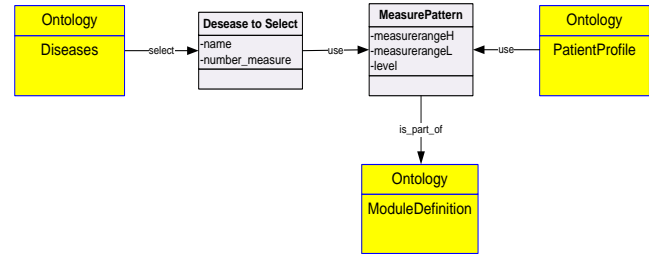


Figure 1. Structure of Measure MobiPattern to generate measure interface.

One example of a MobiPattern is represented in the figure 1, each MobiPattern allow the generation of each Modules that compound the final application. In this figure, we represent a MobiPattern to generate the interface corresponding to capture of measure for different diseases. Each disease has a name (blood pleasure, diabetes, temperature, etc.) and a number measured values (two or more values). The definition of each MobiPattern is generic, depends on the requirements of each disease.

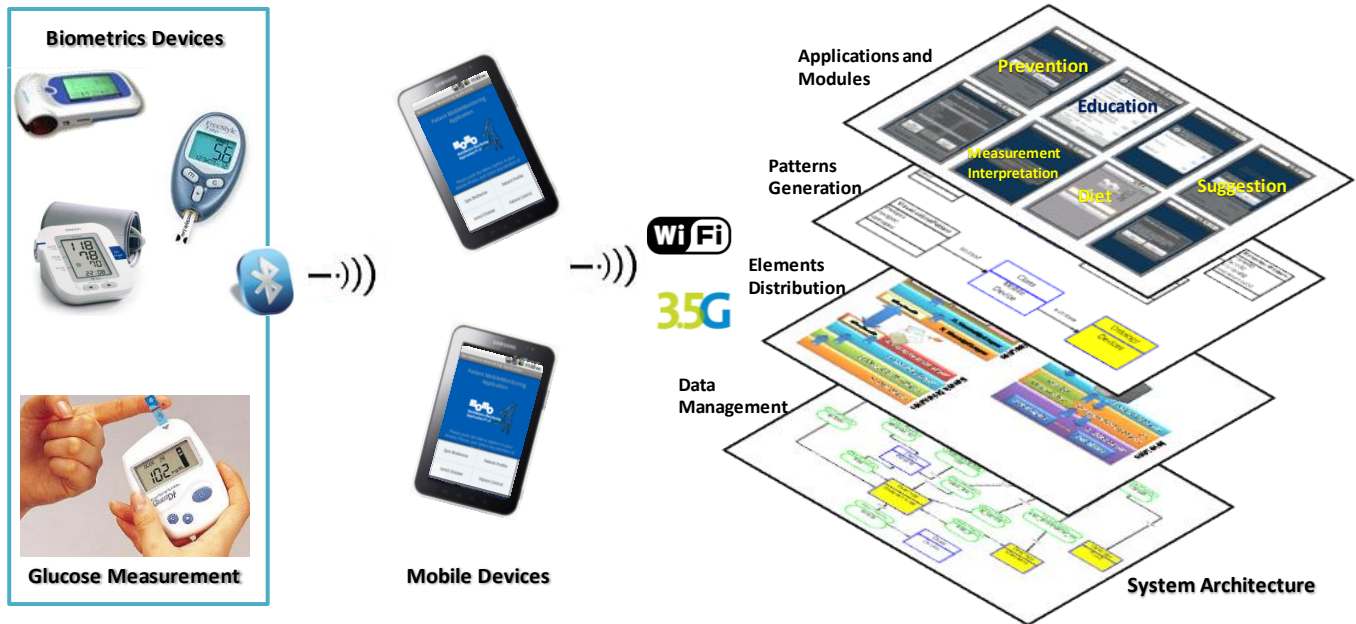


Figure 2. Distribution and function of the System Architecture

D. Elements Distribution

The inclusion of these applications has the purpose of demonstrating the system's capability of transmitting data collected in real time from a device, delivering the data to a remote system, while at the same time locally storing data from another device. It was also a way of testing the developed interface. We have distributed the elements of the framework in layers. In different areas [9] [10] has been implemented using a layered architecture allowing for greater interoperability of the entire architecture and facilitating standardization in development.

In our research, as shown in Figure 3, we have defined and developed a layered architecture within our system architecture. This architecture is distributed through the three main elements: biometric distributed layers, mobiles distributed layers and system architecture distributed layers. Each of the main layers and sub-layers defined functions are shown in the following aspects:

- **Communication:** this relates to the technical possibility that both biometric and mobile devices can communicate. This communication is based on two layers of communication that we have defined: negotiation and transmission. To enable communication between devices those have two physical media. Bluetooth communication is used for communication between the biometric device and the mobile device. The network communication (in some cases global area network, WiFi and 3G) is used for transmission between mobile devices and system's architectures. All devices used must be able to communicate. This communication channel will negotiate the terms of communication, which establishes the formal aspects of each device and the package delivery specifications (size, headers, encryption type, etc.). After these issues are negotiated between the two devices only then would the transmission of the data required is permitted, making the biometric device the transmitter and using the mobile device as a receiver.
- **Security:** other aspects considered while developing our layered architecture, was the security of our data transfer. Some researchers proposed solutions which we evaluated before choosing the most appropriate solution to our architecture framework. Berkeley University of California proposed a security method for WSN (Wireless Sensor Network) called TinySec, which provides encryption and authentication [11] [12]. It consists of two sub-modules: one for encryption and another for authentication. Security in our architecture is related to the protection of transmitted data captured by the biometric device and the subsequent sending of a measurement safely into the biometric device. To transmit data between mobile and biometric devices we use Bluetooth, into which we will implement security protocols.

- **Application development:** all applications within our layered architecture will be able to trace the same level regardless of the technology hardware. That is why the location of the developed applications (modules integrated into one final application) must be placed at a level of identifiable architecture. Application development defines three levels of operation. These standards specify the location of each of the modules generated based on the MobiPattern designed. The application layer consists of n-sub-layers with functional characteristics of the application.
- **Heterogeneity:** many devices with diverse communication capabilities must live in the same environment or be able to communicate with the biometric devices without any difficulty. For that reason, the communication technology used is Bluetooth.

This was discussed to allow the integration of new communication technologies and data transmission at the lowest levels of our layered architecture. In the event that a biometric device has another communication technology, the mobile application may be used manually enter the values resulting from a measurement.

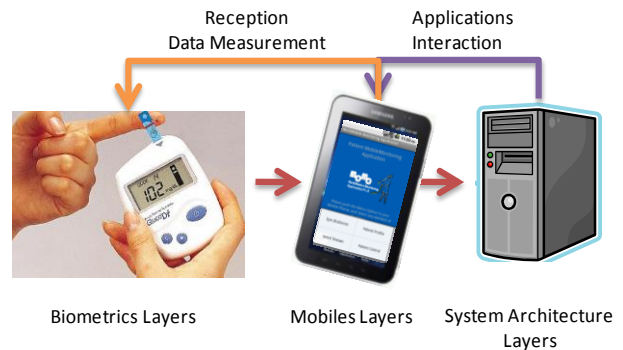


Figure 3. Functionality of system architecture layers.

E. Data Management

Depending on the information stored in the patient medical history, different modules are upgraded or appended with new incoming data.

All activity development for the patient is stored on a server; it is possible for the doctor to review information about each patient. The doctor has information about the last measure, activities, recommendations generated, alert with date and hours for patient control.

IV. SYSTEM FUNCTIONALITY

The figure 4 shows the functional flow architecture of the architecture developed. First of all, it defines the relationship between each MobiPattern and Ontologies through the Framework core. Then, each module is generated adjusted to each type of disease, according to the patient required to generate a final application is embedded in the patient's mobile device. This application is synchronized with the

biometric device in the case that measurements are obtained from a device's with communicate and transfer technology. If the patient doesn't have a biometric device with communication technology, the collection of data will be done via the keyboard of your mobile device. Thus begins the functionality of the monitoring application with the biometric and mobile device. The system architecture for a patient monitoring provides connectivity via Bluetooth, as

shown in figure 5a, with biometric devices (Glucose Meter) providing they have this type of connection, it facilitates the reading of a patient's vitals. In cases where a biometric device (Glucose Meter) has no Bluetooth connectivity, the application offers the possibility of introducing on-screen values generated by the biometric device, as shown in figure 5b.

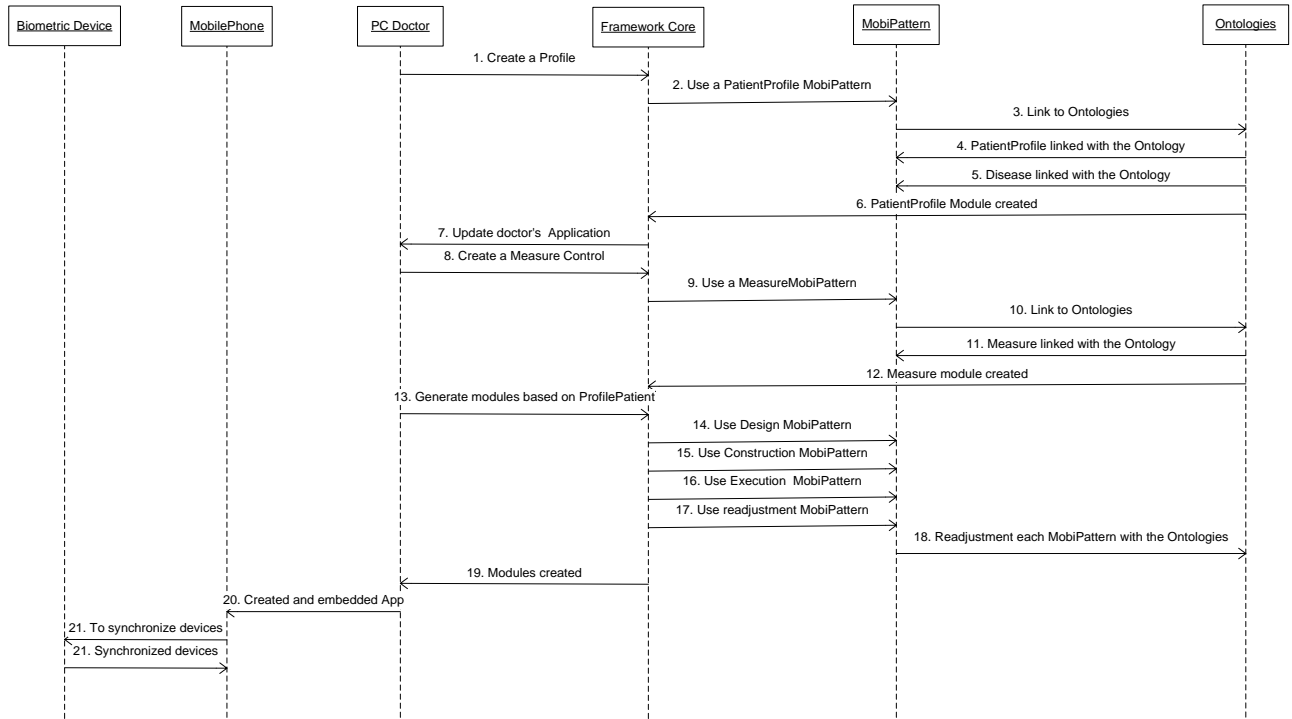


Figure 4. Functionality flow of the Architecture

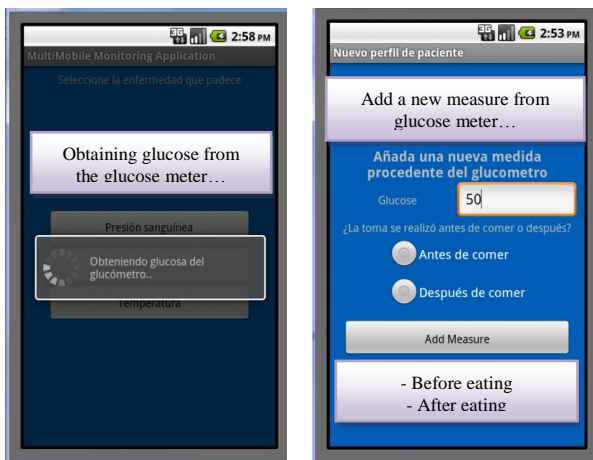


Figure 5. Snapshot of a. Reading vital signs via Bluetooth, b. Reading vital signs via keyboard.

After a glucose level is obtained at certain times, the system interprets the glucose value in three different ranges

(low, normal and high) according to the values established for diabetes, as shown in figure 6a. Each group has an associated range of issues that allow patients to determine if it has changed or not from expected glucose levels, as shown in figure 6b. This incidence is stored in the database and then may be reviewed by the physician at the visit.

A patient with diabetes should combine diet and exercise to control their glucose levels, which is why the application asks the patient if they exercised, as shown in figure 5c. Depending on the level of glucose obtained from the glucose meter, a recommendation for or not to exercise is made.

If the patient is in a range that does not allow for exercise the system will recommend the patient not exercise and continue to monitor glucose levels until reaching a permitted range. When glucose levels are within an acceptable level, the system asks the kind of exercise you intend to do, as depending on the type and duration of each exercise, it will show different recommendations for controlling glucose levels, as shown in figure 6d. For example, it may recommend how many carbohydrates must be eaten by volume and weight, as show in Figure 6e and 6f.

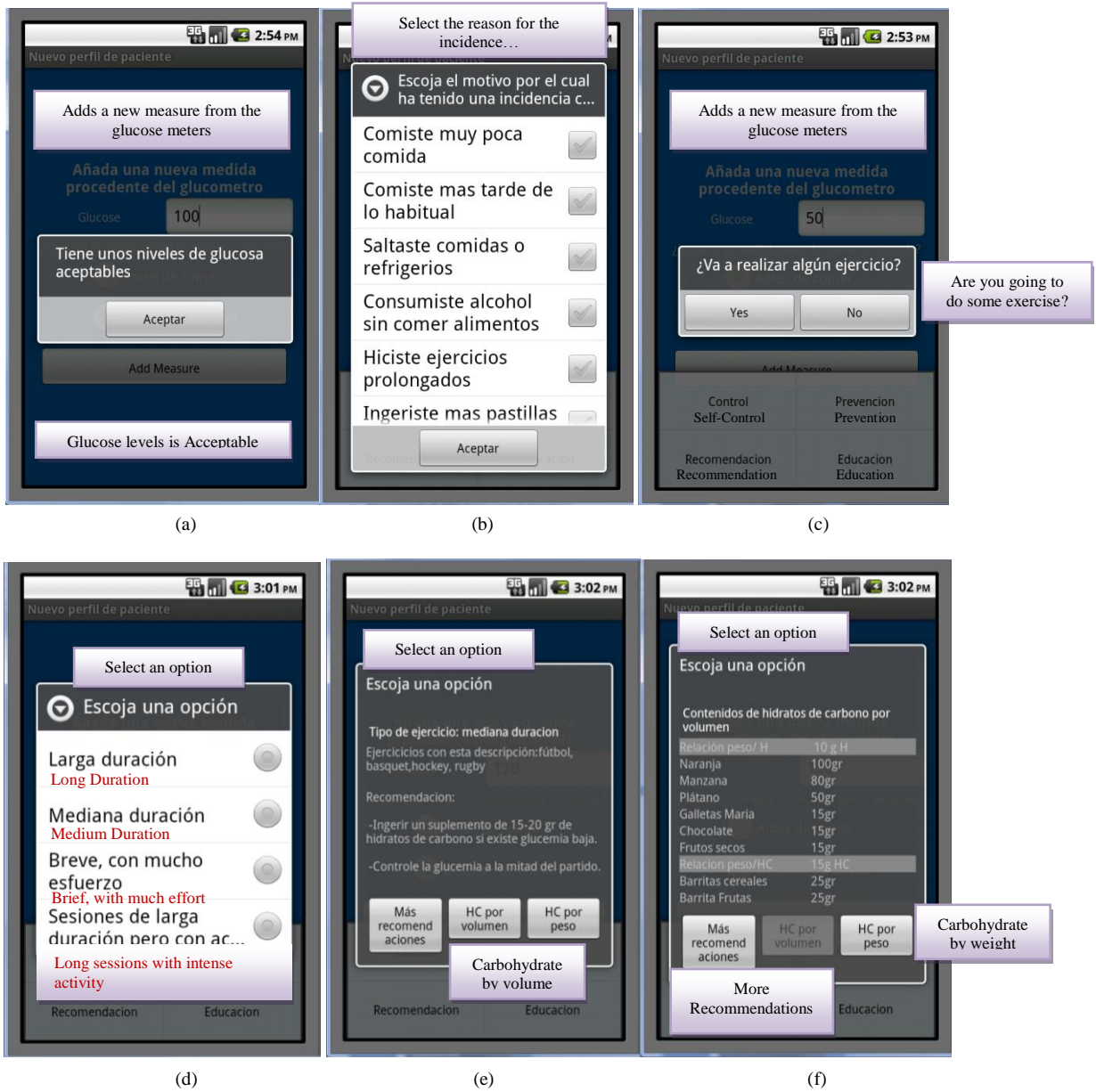


Figure 6. A snapshot of the complete functionality of the system architecture for a patient with normal measurement.

Besides the generation of recommendations and suggestions for patient management, our architecture offers patients the ability to view the history of your measurements taken at any time during the day.

This allows the patient to analyze the behavior of their disease with respect to medical controls for variations in their glucose measurements. As shown in Figure 7a, the patient may display a table with information about the day when the measurement was obtained and the value of the measure along with the range in which it is located. In the same way, you can view graphs the behavior of glucose at

different times of the day, allowing evaluation of possible changes in the health surveillance, as shown in figure 7b.

This group of applications has been developed merely for the demonstration prototype. The aim of this prototype was (as described above) to collect live data from the devices and transmit it via Ethernet or Wi-Fi to a computer. Collected data should then be displayed in a set of graphical interfaces.

In figure 8, you can see how a patient with diabetes uses the mobile monitoring application to control their glucose. First of all, the patient obtains a blood sample and puts it in the Glucose Meter. Once the blood sample is read, the Glucose Meter displays the glucose level of the patient at the

moment. This patient was in a "normal" range with a value of 100 mg / dL before meals.

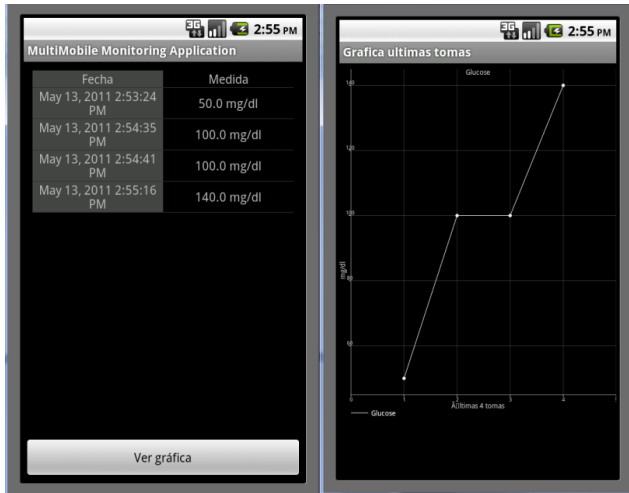


Figure 7. Snapshot of a. Table view of the measurement and b. Graphical view of measurement.

The patient uses a glucose meter “GlucoTel” with Bluetooth communication, which transfers the value of the

blood glucose to the mobile phone “GeeksPhone One” with an Android 1.5 operating system.

The glucose measurement is sent to the mobile phone, which interprets it according to the ranges established for diabetes and shows the recommendations and suggestions for the patient. It is here that the mobile application starts interacting with the patient by offering timely advice to monitor and control the disease.

The patient can see the list of recommendations for diet, exercise, medications, and preventive care activities by only touching the mobile phone screen. Also, they keep glucose levels under control by constantly viewing certain sections of the table and graph for the measurements obtained earlier.

V. EVALUATION

This solution has been designed, evaluated and validated by a group formed by five patients. The goals of this evaluation have been, on the one hand, to show if this solution is accepted by patients. This evaluation was applied to patients with diabetes, where the phone used to monitor their blood glucose was used in conjunction with their diabetic notebook annotations.



Figure 8. Diabetic patients using the monitoring application for the control of blood glucose.

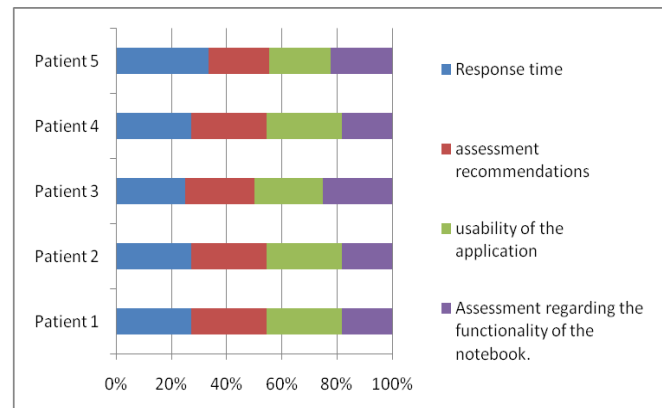
The ages of the patients were in the range of 40 to 50 years of age, having on average three years experience managing their disease.

Based on the first prototype, patients provided their feedback, comments and recommendations, which have been used for the design of the actual solution. Aspects were evaluated as:

- Response time of application;
- Assessment of the recommendations generated;
- Usability of the application for the novice user;
- Assessment with regard to the functionality of the notebook.

As shown in graphic 1, with established scales of 1 to 3 with the following ratings (1 = poor, 2 = moderate, 3 = good) each of the aspects evaluated, resulted in patients considering the response time of the application as well. As to the value

they gave regarding the reality of the disease, patients gave a normal value.



Graphic 1. Evaluation of functionality and usability of the application.

Regarding ease of use for the mobile applications, patients feel that the application is easy to use, since the interaction they have is very simple and short, since the mobile application responds mostly automatically. Lastly with respect to assessing the use of the application compared with the notebook used by diabetics, it showed that there is still some opposition to leave it behind and they feel safer having their entries on paper.

VI. CONCLUSIONS

The domain of Ambient Assisted Living systems is a very promising but also very challenging one. In order to enable people with specific needs to live an independent and safe life, the systems must cope with a series of characteristic user and environmental challenges.

They result in a set of service and system qualities that apply for all technical AAL solutions. Prominent qualities are available, dependability, and adaptability. Tradeoffs between these qualities complicate the engineering of AAL solutions substantially. Driven by affordability and scarce resources it is clear that AAL solutions will somehow follow a “just enough quality” rationale.

Monitoring patients with chronic diseases; as in our case a patient with diabetes; are of great importance in order to maintain constant monitoring of the patient and facilitate their daily activities. The developed system architecture, offers the ease of control for each patient, with minimal interaction necessary and appropriate responses to changes in glucose levels. This architecture provides scalability for use in other technologies and types of diseases, where it is necessary to obtain vital signs and controls for the subsequent use by the patient's physician. We are working on other types of diseases to generalize our architecture to allow monitoring of different types of vital signs based on the type of disease being treated.

The evolution of the technology allows for the definition of new advanced systems, to reach a more accurate treatment of chronic diseases such as diabetes. In addition, our systems architecture allows the definition of solutions closer to the patient and nurses, which allows an easy integration and acceptance of them. Our evaluation has presented that patients are very interested and open to these kinds of solutions, and consider it very useful, recommending us to introduce it in hospitals.

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REFERENCES

- [1] Georgia Institute Of Technology. AWARE HOME [Cited; Available From: <http://awarehome.imtc.gatech.edu/>
- [2] Kientz, J.A., et al. The Georgia Tech Aware Home. In CHI '08 Extended abstracts on Human Factors in Computing Systems (Florence, Italy, April 05 - 10, 2008). 2008. New York, NY: ACM.
- [3] Choi, M. and B. Jones, Remote Home Health Monitoring Management Using Smartphones, In Poster Presented at MHEALTH Summit 2010. 2010: Washington D.C.
- [4] University of Virginia. Smart IN-HOME Monitoring System. [Cited; Available From: <http://marc.med.virginia.edu/projects/smarthomemonitor.html>
- [5] Intel Corporation. People Center Innovation. [Cited; Available From: <http://www.intel.com/about/companyinfo/healthcare/people/research/approach.htm?wapkw=%28alzheimer%29#>.
- [6] University of Roschester. Center of Future Health. [Cited; Available From: <http://www.urmc.rochester.edu/future-health/>.
- [7] López-de-Ipiña, D., et al., ELDERCARE: An Interactive TV-BASED Ambient Assisted Living Platform, In Activity Recognition In Pervasive Intelligent Environments, Atlantis PRESS. P. 111-125.
- [8] Villarreal, V., J. Bravo, and R. Hervás, Towards Ubiquitous Mobile Monitoring for Health-Care and Ambient assisted Living, In International Workshop on Ambient Assisted Living, 2010. 2010: Valencia, Spain.
- [9] Barbarán, J., et al. RADMOTE: A Mobile Framework for Radiation Monitoring in Nuclear Power Plants. In XXI International Conference on Computer, Electrical, and Systems Science and Engineering CESSE 2007. 2007. Vienna, Austria.
- [10] Crossbow-Technology-Inc. <http://www.xbow.com>
- [11] Lewis, P., et al. The Emergence of Networking Abstractions and Techniques in Tinyos, NSDI04. In First Symposium on Networked Systems Design and Implementation. 2004. San Francisco, California.
- [12] Karlof, C., N. Sastry, and D. Wagner. TINYSEC: A Link Layer Security Architecture for Wireless Sensor Network. In Second ACM Conference on Embedded Networked Sensor Systems, SENSYS 2004.