"Imagine a world where technology helps solve the toughest problems facing us today"

EMBEDDED DEVELOPMENT

ROUND 2

E-DOCTOR

A low cost and easy-to-use medical diagnostic box

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SUMMARY

E-DOCTOR is a low cost device focused on the disease prevention and support to facilitate medical screening in disadvantaged areas. It is conceived to be equipped with a variety of peripherals performing different types of medical inspections: blood pressure, temperature, heart rhythm, pulse oximeter and any other portable sensor that can enrich the overall functionalities.

1 E-DOCTOR SITUATIONAL ANALYSIS

1.1 Problem Description

Endemic diseases and tough life condition are one of the major issue faced especially in the south of the world. Malaria, Cholera, HIV, Diabetes and other serious diseases are one the main cause of death in many Countries in Africa, Asia and other less developed areas in the planet. Fighting diseases proliferation is one of the eight strategic objectives declared by the United Nations and we believe that new technologies, coupling information technology and telecommunication, can be useful to mitigate some of the concerns in the poorest countries. Preventing diseases is certainly a means to decrease mortality and help population to start-up a minimal medical network addressed to children, pregnant women and people in general. Our project, described in the following paragraphs, will present how our team believes that embedded technologies can contribute in step over on this long road.

Mortality in underdeveloped Countries is caused by both infective and not infective diseases. As far as infective disease is concerned, HIV represents the most dangerous and contagious and it is the primarily reasons of death in poor Countries for childhood: unfortunately the poorest and more marginalized people are denied all the fundamentals rights about cure and disease prevention.

In 2007, 2.1 million people died because of HIV and 2.5 million got the infection. In the same years 2.5 million children turned to be HIV positive. Everyday 6800 people are infected by the virus, 96% of them are in Countries where the average people income is extremely low.

Unfortunately, also the non infective diseases have fearful statistics. As a matter of fact, Diabetes is one the Third World Warning and it kills one man every 10 seconds; 380 million people will become sick in 20 years, especially in the Third World where the diffusion of this disease has no serious obstacles. Associations like Unicef and WHO (World Health Organization) since many years have been trying to find different solutions to defeat endemic diseases in those Countries. The International Diabetes Federation reports that before 2025 almost 80% of the all diabetes cases in the world will be in the poor Countries. This shows how this non infective disease is considered as dangerous as HIV, Malaria and Tuberculosis.

Lack of diagnostics and therapeutics tools are certainly one major reason for such a high mortality. We have been considering a lot how technology could help improving this condition on a worldwide scale and decided to steer our project to make a proposal on a low cost, easy-to-use, robust “medical” box help to contribute filling the gap of early diagnostic in scarcely populated areas.

1.2 Project Analysis

E-DOCTOR is a low cost device focused on the disease prevention and support to facilitate medical screening in disadvantaged areas. Many times one of the toughest activity is to reach population spread over a wide territory in areas where transportation in unsafe and difficult. Moreover, many populated areas

are not served by medical personnel and therefore developing prevention mechanisms and procedures is even harder. Therefore, a solution can be a unmanned equipment, easy to use and secure enough to guide people in performing self inspections and tests.

E-DOCTOR is the client device in our system; it is conceived to be equipped with a variety of peripherals performing different types of medical inspections: blood pressure, temperature, heart rhythm, pulse oximeter and any other portable sensor that can enrich the overall functionalities. Sensors are connected with the main unit using standard interfaces such as USB, serial or Bluetooth. In the future, following the technology progress, other sensors can be plugged to the main unit.

E-DOCTOR has been designed to work in rural areas where power consumption may be an issues as well as land telecommunication lines (ADSL). Therefore, in our picture we do consider alternative means of connecting E-DOCTOR to the application servers such as the satellite: nowadays there are many satellite providers selling bandwidth and connectivity in rural areas at affordable prices. E-DOCTOR does not need to be permanently connected: connectivity is needed on a per demand basis whenever data needs to be sent to the remote servers. The system architecture is shown in Figure 1.

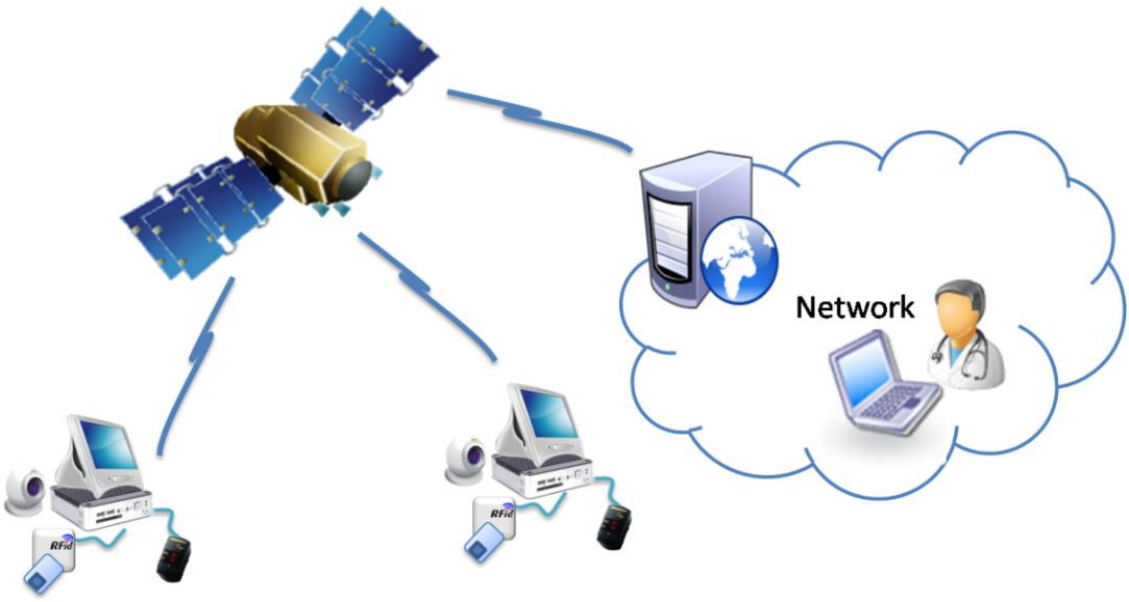


Figure 1: E-DOCTOR system architecture

Users shall be easily identified and securely authenticated by RFID card reader. A smart card with the patient's credentials (and eventually a picture) storing some specific authentication data can be a means. E-DOCTOR allows for different levels of authentication to set different type of users:

- **Patients**. These are the main users, they should have an easy and robust way to access the system. Privacy of data shall be properly ensured;
- **Authorized medical personnel**. These are people "in the field" with the privileges of accessing any data stored in the client for either maintenance or medical pre-screening.

Authentication on the client is facilitated by the usage of a Microsoft SQL Server CE, containing information on users profiles.

E-DOCTOR medical application is linked to a Central Operating Center (COC) most likely through a satellite linkage that is accessible also in rural areas. The application interface used to access the DB will be implemented by a WebService. We decided to employ a WebService because it is defined by the W3C as a software system designed to support interoperable machine-to-machine interaction over a network. This server will have a large database with all the analyses and relative diagnosis. The server also allows for archiving historical data thus allowing doctors to consult previous analyses and retrieve statistics on a particular area.

E-DOCTOR also use a webcam as an external peripheral: this is important because it allows users to show doctors a particular emergency situation such us an injury, erythem, etc. These pictures will be sent eventually along with the analyses to the central server and made them available to clinical specialist for further investigations.

On the server side, most likely implemented in a hospital, there is the application used by doctors to inspect the analyses. Such an application will be built using Windows Presentation Foundation (WPF).

The operating system used on E-DOCTOR (client) is Windows CE 6.0 R2, a scalable, 32-bit operating system that integrates reliable, real-time capabilities; is the core of our embedded device. Windows CE 6.0 R2 provides the following benefits:

- Low power consumption. As already mentioned this is a critical feature in areas where electricity may be distributed discontinuously.
- Cost effectiveness. E-DOCTOR is dedicated to rural and disadvantaged areas wher cost of infrastructure is a major issue.

1.3 User Experience

As mentioned before, E-DOCTOR is conceived and designed for helping medical organizations in disadvantaged and rural areas in the world. It could be also used to monitoring elderly people with no possibility to go to the clinics. They stay at their home and the doctor will be able to monitoring them from distance. This latter possibility is a key priority in the e-health system of every advanced Country worldwide. As a matter of fact, the user experience in these two categories of devices can be different, therefore E-DOCTOR shall be designed and developed to easily change the graphic user interface and adapt to different users' categories.

Authentication Form

1.4 Market Analysis

According to Research and Market (http://www.researchandmarkets.com/) "there has been a phenomenal growth in the Medical Devices market owing to new innovations in different sectors of this market. Advancement of technology has catered to the development of new devices for the healthcare sector. Adoption of these devices can eliminate the need for certain cumbersome traditional surgical and diagnostic procedures. With the aid of advanced technologies, innovative devices have been provided in the medical field. Advanced medical devices that aid diagnosis and surgical procedures have been implemented by the healthcare organizations worldwide. Further, growing healthcare costs in the face of financial crisis is primarily driving the adoption of modern medical equipment to reduce operational and storage costs and deliver quality healthcare services".

The device we are looking at is right trying to reduce the "need for some bothersome diagnostic procedures" by facilitating the usage on the field and allowing population living in underdeveloped Countries to have an easy access to the most common diagnostic principles.

There is another aspect that we are considering: the Health Aging organization (http://www.healthinaging.org) reports that "the number of senior citizens in the United States is rapidly increasing. During the 20th century, the US population under age 65 tripled, but those 65 and older increased by a factor of 11. The actual number of seniors grew from 3.1 million in 1900 to 33.2 million in 1994. Plus, this number is expected to more than double by the middle of the next century, to 80 million people. By the year 2030, about one out of every five Americans, or 20% of our population, will be a senior citizen". Aging is a common trend world wide and it testifies the fact that light and easy-to-use home diagnostic systems can become a key instrument to run medical inspections remotely, keep chronicle patients under control and allow for an affordable and widespread national health system.

In summary the information we have found demonstrate that:

1. technology is ready to allow mass production of low cost medical devices addressed to early diagnostic in the field;

2. humanitarian organization, such as Doctors Without Borders, confirm as prevention, in some diseases like cholera, is the only means to defeat the virus (http://www.doctorswithoutborders.org/news/issue.cfm?id=2390). Beyond any market data, the emergency in poorest Countries raises an ethical issues against the richest Countries to invest in this sector;

3. worldwide population in the wealth Countries is aging and chronicle diseases or severe disease such as Alzheimer make it necessary to develop small, portable and easy to use diagnostic equipment to allow elderly people to run an autonomous life and the government saving money in useless hospitalizations.

1.5 Cost Analysis

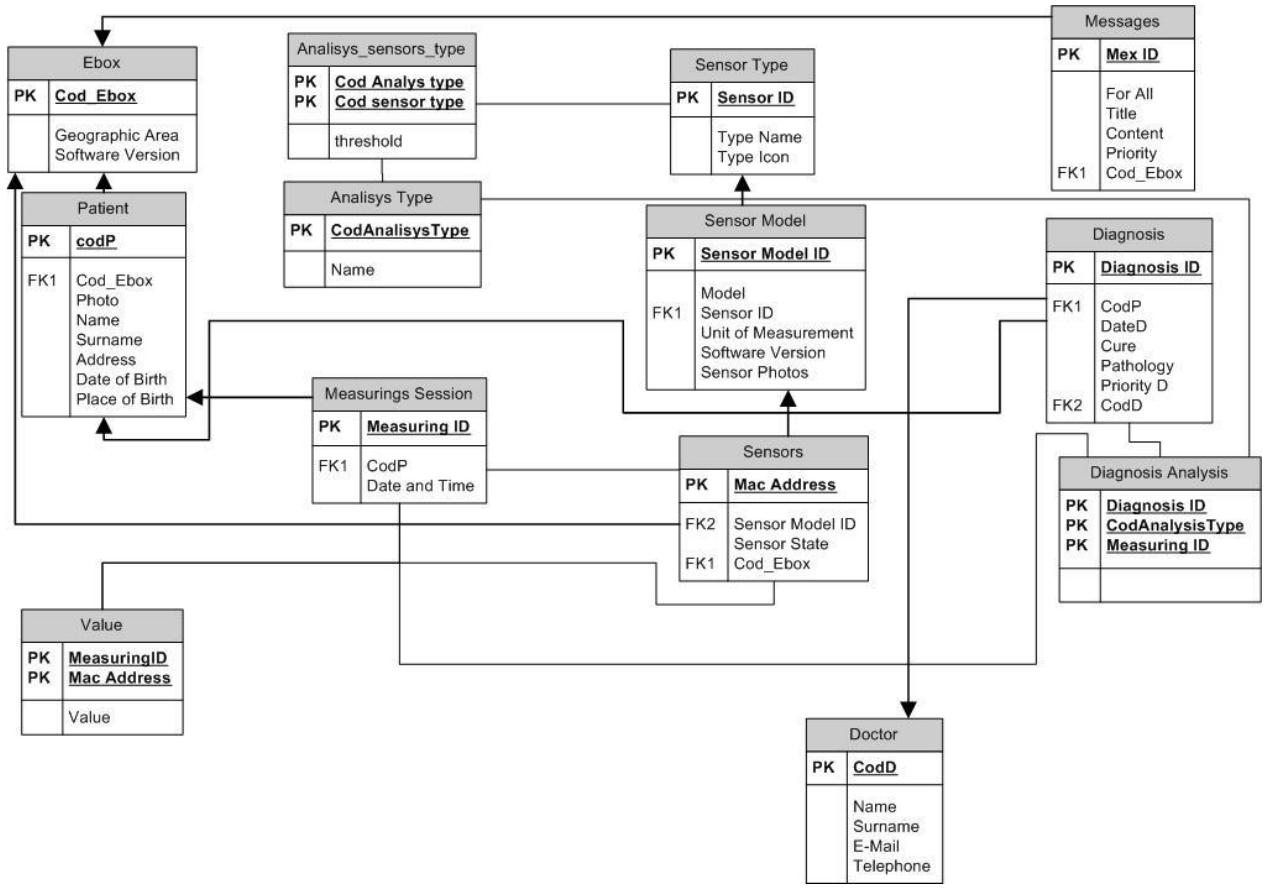
eDoc prototype system is made by single components and the cost list (per unit) is showed below.

Components	Price
eBox-4300 JSK	161.00 €
Logitech Quickcam® Pro 9000	109.00 €
Ear & Forehead Thermometer TD – 1261A	50.00 €
RFID card reader	30.00 €
7" USB Touch Screen LCD Monitor	200.00 €
Total price:	**550.00 €**

The total cost could change by including more medical sensors and/or other type of devices. Of course, this is the cost for a single unit, it would decrease significantly with a mass production, in fact the single components could be integrated on the device or customized.

2 TECHNICAL ARCHITECTURE

2.1 DATABASE ANALYSIS



Our database is composed by 13 tables that are necessary to the proper functioning of the program. The E-Doctor table is defined by: a Cod_Ebox (primary key) that uniquely defines an Ebox, geographic area that shows information about the location of E-DOCTORand Software version that is an important parameter to future software update.

Patients are uniquely defined by CodP, that is the code of their badge, they are also associated to a Cod_Ebox to identify the E-DOCTOR device that makes analysis to that patient since doctor with the client program can click on a specific E-DOCTOR and retrieve through a query all people that are associated to that device. Patient table also show generic information about patient like Name, Surname, Address, etc..

There are many sensors connected to E-DOCTOR and the database contains 5 tables (Sensors, Value, Measuring Session, Sensor Model, Sensor Type) that are necessary to identify and retrieve information from them. In Sensors table we can find sensor MacAddress (primary key), **sensor state (idle or active)**, Cod_Ebox (Foreign Key) necessary to know to which E-DOCTOR is connected sensor and Sensor Model ID

(Foreign Key). Value table shows information about measuring session and sensor that do measuring (MeasuringID and MacAddress both PK) and measuring value. This table is important to connect Measuring Session table (that contains information about CodP, measuring Date and Time and MeasuringID) and Sensors table. In Sensor Model table there are 6 columns : SensorModelID(PK), Model (many sensors that have the same function may return different parameters due to model to handle this situation we insert this column) , Unit of Measurement (there are many types of sensors connected to Ebox, each component has a different unit of measurement), Software Version, Sensor Photos (this column is used to save photos retrieve by webcam or another device that makes images. If the sensor doesn`t produce any image this parameter is set NULL), SensorID(Foreign KEY from Sensor Type table).

A strength of our project is scalability: you can make any number of connections to E-DOCTOR, through software updates E-DOCTOR program can identify new device and make it available. In this way Sensor Type table allows , if is present into database, to display into program both a new sensor type icon (Type Icon) and new sensor type name (Type Name).

E-DOCTOR can make many analyses that are described into Analysis Type table composed by two columns: CodAnalysisType (Primary Key) and Name (Analysis Name). Each analysis may be composed by many sensor measures, so in analysis sensor type table there are CodAnalysis type, CodSensorType (both primary key) and threshold (important to see if value of measurement is dysfunctional), in fact through database queries a doctor with program client can verify if a patient has or not a specific disease.

After an analysis or a measuring session, all information is saved into database and can be sent to server. When a Doctor wants to retrieve information about one or many patients, he, through program client can make a connection to database. Doctor Table shows information about Doctor like his badgeID (CodD), Name, Surname and so on. After reading analysis results doctor can write a diagnosis: into diagnosis table are saved diagnosisID (Primary Key),date of diagnosis(DateD),code of doctor that write diagnosis (CodD foreign Key),Pathology,Cure to disease (Cure). For each diagnosis doctor can set priority (PriorityID on the table). Diagnosis_Analysis table associates diagnosis table with Analysis Type and Measuring Session tables, to be traced, for each diagnosis, which analysis belong.

The last table's aim (Messages Table) is communication with E-DOCTOR through messages that doesn`t belong to a specific diagnosis or to a specific patient, but may be nursing care to a village in which E-DOCTOR is located or to all E-Boxes(For All columns). To each message doctor can set priority(High, medium, low).

2.2 E-DOCTOR specifications

The eBox-4300 which is interfaced to various hardware modules is running on the latest Windows Embedded CE 6.0 R2 operating system. The software running in the system is written based on both managed and unmanaged code providing the intelligence controlling the Intelligent Mobile Robotic Monitoring System.

2.2.1 Windows CE Image

The image is built based on modules and components from ICOP eBox4300 BSP, Core OS modules, Device Drivers and 3rd Party components

ICOP eBox4300 BSP

- *VIA Chipset Drivers*: These standard drivers to provide native VGA and audio support

Core OS modules

The following list the few important components to support our applications as well as device drivers running in our system

- *Microsoft Compact Framework 3.5:* Compact Framework provides a rich set of classes to rapid development, which made possible for us to design the input application in little time.
- *C Libraries and Runtimes:* C runtimes is needed to support running of native user and system application
- *Wired Local Area Network:* LAN support for communication over the Ethernet based network.
- *Core OS services*: These includes device manager, display support, serial port support, USB host support etc
- *File Systems and Data Store*: These are needed to support RAM and ROM files system and Hive based registry as well as storage manager to support USB, CF based mass storage
- *Shell and User Interface:* Shell are included to provide easy maintenance and debugging support when LCD monitor is connected to the system. Not necessary in the release version.
- *Graphics and Multimedia Technologies:* Streaming Media Playback and Video Codecs and Renderers (MPEG-1 Video Codec and Video/Image Compression Manager) is needed for webcam streaming. JPEG and other image decoder to make webcam snapshot.

Device Drivers

Device drivers are used to support the operations of the IO devices integrated in to our systems.

- *PCI Bus:* These drivers provide bus support for devices connected to the PCI bus
- *RealTek RTL8139*: The device driver to support the onboard Ethernet module with RTL8139 chipset
- *ATAPI PCI:* These will provide ATA support on devices connected to PCI bus

- *USB Host Controllers:* This will enable client USB devices like thumb drives to be plugged on to the system
- *Serial:* This will enable application to write to the serial port for sensor and robot control
- *Bluetooth Profile Support and Protocol Stack:* These will enable application to use Bluetooth to communicate with sensors.

3rd Party Components

- *ConMan x86 Files Components* : Connection manager components are to support the deployment of the executable files over the Ethernet connection

Processor and Peripheral

- *eBox-4300*: The eBox-4300 is the heart of the embedded system, where eDoc main functions are implemented.
- *Logitech QuickCam® Pro 9000*: This peripheral allows to take snapshot that will be sent to the doctor.
- *TaiDoc Sensors*: these sensors are used to make medical measurement.
- *RFID card reader:* by a personal card, patient or authorized personnel, can be authenticated.

Central Operating Center (COC) Technologies

The server side applications that are the fundamental backbone of EMS are:

- *Webservices:* to allow eDoc and Doctor Client Interface (CLI) to connect to the common database.
- *Microsoft SQL Server CE*: Reliable data storage such as user accounts, communities, diagnosis, information and data.

3 FLOW CHART ANALYSIS

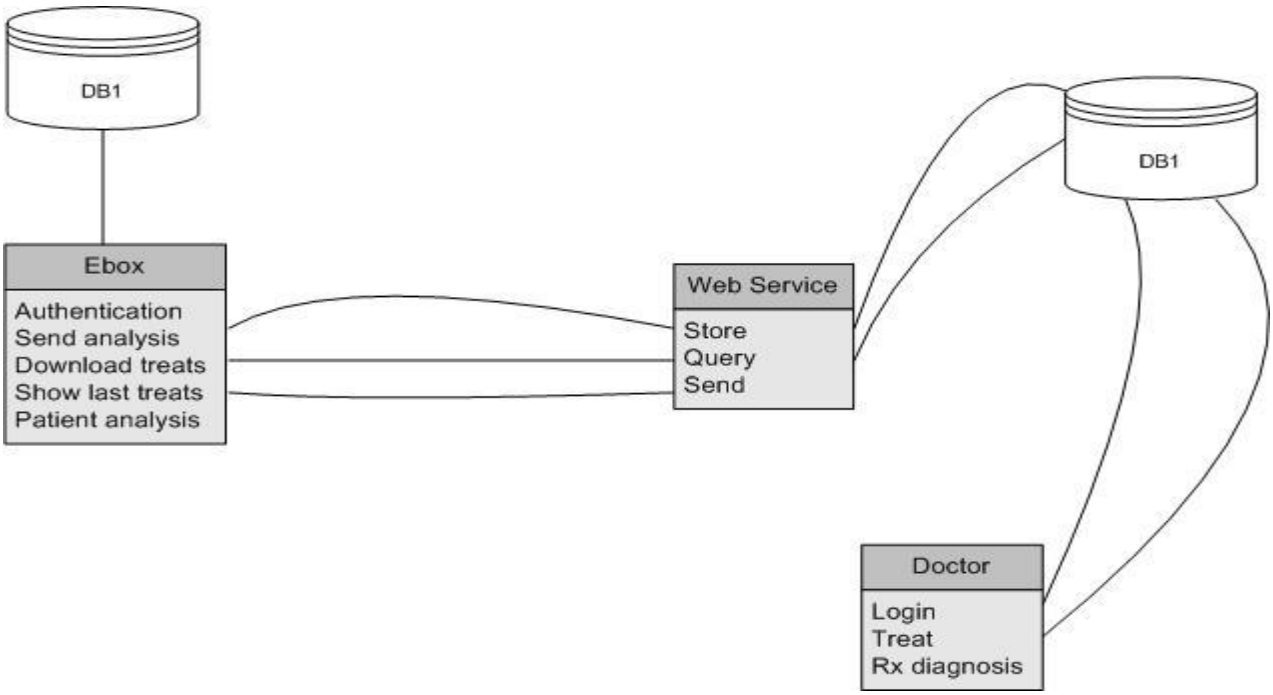
In this section we describe in depth how we have built the program analyzing all the steps and procedures as we can see in the flow chart below, then we present the unique database , the real core of our work, that is implemented into the server and into the eBox, used to develop e-doctor (see the E-R below).

3.1 Flow chart

E-doctor, at the end, is composed by three actors: E-Box, Web Service and the Doctor. They play different roles and provides vital functions but, although they are independent, an important aspect is their

cooperation in order to run correctly the program. Cooperation is a crucial task and it is handled by database, known as DB. To better understand their singular functions, now it is time to visit and understand every single actor.

E-Box: It is the real hardware device and it provides a lot of functions such as: Authentication, send analysis, download treats, show last treats and patient analysis. To improve its functionality it has a lot of sensors in order to analyze patients and it makes possible to do cross-checks. Its importance goes on in fact it is the functional unit in every village and it must handle all the interactions between the e-doctor and the patients. In the village it is important to mention a crucial character able to use all the features of our tool as well as to understand the values and the treats, thus a sort of nurse. After this introduction in which we have listed ebox's features we dive into what and how ebox really does. The first operation is authentication and it is based on a personal badge, the patient in fact will pass this object in a badge reader so, at this point, the ebox will do a query to DB and retrieve information about the patient. Then the analyses can



start and at evening or anyway at a fixed hour of the day the ebox sends all the data to the web service that runs on the server, this action is done due to economic reasons as well as to don't waste bandwidth, in fact, e-doctor is designed for poor area where the digital divide is a real problem. Ebox checks once a day if, in the server, there are new treats related to its analyses and if they are present it downloads them. It is also possible to view the last ones to speed up a consultation without losing all the treats' history.

Web Service: It is the software coded by E-Team using C# language and it provides the interface between ebox and server and between server and the doctor. Its functions are: store, query and send. The storing aspect saves all the information used by e-doctor in the hard disk of the server, a raid technology is advised due to the importance of this node in the core of our program. Web service handles the relationship with

the DB in particular it give us a smart mechanism to retrieve our information using queries, so the WB is the application that asks to the DB and gives back to us the answer. It is important to underline how the WB sends back us the information in fact it gathers the last one and, at a fixed hour, it creates a connection with the ebox or with the doctor. When the query is over we have to handle the sending aspect, in our case we have built a TCP/IP connection, due to security reasons it is a good choice to harden the server and in particular it is reasonable using https and, in this way, our data are a cipher text and we use the strength of the secure socket layer. However our idea is flexible and the implementation is decided by the developers, thus some decisions such as protocols to use in link, network and transport layer or the policies to handle the sending, once a day or more times, must be decided knowing the single scenario.

Doctor: He/She is the human aspect of the program. He/She provides the tears and due to e-doctor his/her work is softer, in fact it makes possible to help people from other villages. This is the doctor's role, he/she considers the analyses and he/she sends a treat. In this brief introduction we have enumerated his/her functions: login, treat, receiving diagnosis. The first step is the login, in fact the doctor must authenticate his/her position, he/she has a privileged account, it consists in querying the database in order to have the diagnosis. Once he/she has this information, the doctor can get to work and in this way he/she reaches his/her distant patients attempting to look after them.

4 HARDWARE COMPONENTS:

About our project hardware components we use the following sensors:

- ✓ **Ear & Forehead Thermometer TD – 1261A**

It is a Taidoc product, two temperature range unit type can be chosen:°C or °F. Temperature range (°C) is 32°C ~ 43°C for ears and 23°C~44°C for forehead with an accuracy of 0.1 °C. It can also detect Ambient temperature. Transmission occurs via Bluetooth.

- ✓ **Logitech QuickCam® Pro 9000**

It is a Windows CE compatible Logitech product, Carl Zeiss ® optics with auto focus for sharp images even with very tight shots. It makes high quality images (8 million pixel) and computer connection is via Hi-Speed USB.

- ✓ **eBox 4300**

The eBox-4300 is a compact and computing device designed for applications where physical space is limited. It can be mounted on any VESA standard fixture allowing it to be secured to desks and other surfaces. Conforming to the VESA mounting enable eBox-4300 to be mounted on the back of most LCD monitor supporting the VESA mount standard and help save precious space in the work place, point-of-sales, point-of-information and other environment.

- ✓ **RFID Reader**

This component is used to authenticated patient or personnel authorized. It's interfaced by RS-232 port.

- ✓ **7" USB Touch Screen LCD Monitor**

Wire Resistive Touch Screen (USB); VGA Input, Supports 800x 600 display resolution; NTSC/PAL Multi-System; On Screen Display Control.

5 TESTING AND PERFORMANCE ANALYSIS

Based on testing and debugging methodology, extensive testing and debugging was carried out in order to identify potential problems with the application. These tests uncovered some bugs in our application. Using Visual Studio debug tool, we were able to run step by step the application and control instructions.

This tools were very useful to write a correct code for Bluetooth communication, because sensor datasheets didn't completely explain how to create a connection with the medical sensors such as the thermometer. After these tests, we have to refine the code to increase the application's performance.

6 PROJECT STATE

E-Team is composed by four students and all participants, during these months, have been working hard in order to fulfill our dream. To handle in the better way this second round we have spilt our works in two parts: GUI and Windows CE image. Manuel and Giampiero have coded and taken care of all GUI related aspects and now, after a lot of weeks, we have a cool and easy to use graphics. This is an important feature to the project and we want to underline how, nowadays, a smart GUI makes the difference to analyze the program quality. This purpose has been successfully reached and we are proud of it.

Mariano and Dino, on the other hands, have studied what is Windows CE and how it works. They have focused their attention on building the image of the customized OS, understanding all the tricks to build it

using Visual Studio and to debug it. This is the core of the system, it is the brain of our eBox and it must cover all the features showed in the previous sections of this report.