Design, Development, Deployment of a Telemedicine System in a Developing Country: Dealing with Organizational and Social Issues

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***Abstract*—Telemedicine means delivering health care services to remote locations by ICT (Information and Communication Technology). Several types of telemedicine systems exist: by this paper, we focus on teleconsulting systems.**

We report here about a telemedicine project in one of the poorest country worldwide, Burundi. After gathering the requirements, which strongly differ from the requirements of a telemedicine project in a developed country, we designed, implemented, and deployed a prototype aimed at providing local physicians of the Hospital of Ngozi, Burundi, with expert second opinions from their colleagues in the University of Verona, Italy, on interpreting ECG signals, ultrasound and X-ray images.

We considered in a seamless way both process- and data-related requirements. Besides the more technical aspects, we also report on some organizational and social issues we faced during the project.

***Index Terms*—Telemedicine; developing country; organizational issues; social issues.**

I. Introduction

The literature proposes several definitions of "telemedicine": the WHO (World Health Organization) in 2009 counted 104 distinct, peer-reviewed definitions of the concept [1]. In this paper, we refer to telemedicine as "the delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities" [1].

Basically, telemedicine systems can be classified according to their main goal. One possible taxonomy includes the following items: remote intervention systems; remote monitoring systems; remote diagnosing and teleconsulting systems; remote education (e-learning) systems. One relevant dimension for the classification refers to the type of communication between the partners: communication can be synchronous or asynchronous, where synchronous connections require a broader bandwidth of the communication channel.

Many telemedicine projects have been deployed in different contexts, both in developed and in developing countries [1], [2], [3]. As a matter of fact, all the countries, both developed and developing ones, can take real advantages from telemedicine. Requirements, goal, success rate, technological environment, skill level of users deeply differ from one context to the other one. Such facets must all be properly analyzed and considered when designing a telemedicine project, and deploying a good project in the wrong context - not the one for which that project has been designed and tailored - may easily result in a failure.

In this paper, we report about a telemedicine system devoted to teleconsultation services (aka remote diagnosing or telecounseling or expert second opinion). Teleconsulting services provide users with a remote consultation, involving doctor-to-doctor or doctor-to-patient communications on a network or video link (e.g., Facetime, intranet, Internet, Skype, etc.), as opposed to the "in person" counseling where no ICT is needed to manage the interaction between the physicians or between the patient and the physician(s). We focus here on a doctor-to-doctor (possibly asynchronous) interaction.

As application domain, we considered the hospital in the city of Ngozi, in Burundi. The hospital, which features some 200 beds, has to face a very limited budget: every admitted patient costs some 10÷12 € per day - typically in Europe the average cost is 800÷1000 € per day. Consequently, resources locally available for the project are very limited.

The choice has been driven by previous experiences of the University of Verona, Italy [4], together with the Hospital of Ngozi in remote education programs. We now mainly focus on teleconsulting for pediatric cardiology, by analyzing electrocardiographic signals (ECG) and biomedical images (ultrasound and X-ray).

In the following, Section II describes the background and the related work; Section III describes the design choices, including requirement gathering, we performed; Section IV describes the architecture of the designed system; Section V reports about the efforts aimed at involving and encouraging local users to exploit the system in the everyday practice; Section VI reports on lessons learnt and encountered bottlenecks, and sketches out some possible enhancements for the system.

II. Background and Related Work

In this section we describe the environment where we deployed our telemedicine project, and some related work.

A. The Location

We briefly describe the nation where we deployed the project, and report on the facilities as detected by our technicians during the local inspections performed at project start up.

1) The Nation: Burundi is one of the poorest countries in the world. In the 2012 charts of countries by GDP (Gross Domestic Product) per capita developed by CIA (US Central Intelligence Agency), World Bank, and International Monetary Fund, Burundi is at best fourth from last and at worst second to last (over about 180–190 total countries) [5], [6], [7]. Its surface is about 27,830 km^2, hosting some 10,557,259 inhabitants (as estimated on July 2012). The average height of the territory is about 1,700 meters above the sea level. Being located very close to the equator line, the duration of the daylight is almost constant through out the year, about 12 hours, and sunrise and sunset times change very slightly from season to season.

Ngozi is one region in the nation, with a population of about 120,000 inhabitants (40,000 urban and 80,000 rural according to the 2008 census [8]). The capital city of the Ngozi region is named Ngozi, too, and it is about 130 km North-East of Bujumbura, the capital city of the nation. In Ngozi, despite the majority of houses and buildings have one or at most two floors, many people live in shacks made up of handmade bricks or obtained from a container.

2) The Technological Environment: We report here some observations performed by our technicians during the first inspection to the local site.

Electric power is continuously provided, apart a few sudden changes in voltage, in the hospital and mission houses. While staying there for 15 days, our technicians experienced two electric power black-outs, lasting at most ten minutes each. During the rainy and thunderstorm season, black-out are more frequent. Water is continuously provided: however it must be suitably treated before cooking and drinking. The Internet connection is quite unstable and very slow, and any big file download will block the connection of other users. File download and e-mail checking can be very slow and frustrating. Use of mobile GSM connection is affordable for small quantities of data, considering the exchange ratio between € and the local currency (Burundian franc).

In Burundi, mobile phones have started to spread since 2000 (while in developed countries that phenomenon started in end of the ’80s and beginning of the ’90s), at the beginning very slowly and then, since 2007, faster and faster, moving from 3,5 phones per 100 people to 26 phones per 100 people in 2013 (e.g. Italy now features more than 160 phones per 100 people) [9].

3) The Hospital: The hospital computing facilities consist of 10 computers, available to all the physicians. An Internet connection is available: after switching to a new service provider, the virtual maximum speed is now 1024 Kbps for download and 512 Kbps for upload (connection tests reported about 250 Kbps for download and 170 Kbps for upload, but the most common download speed is about 160 Kbps). Hopefully, the new Internet connection would suffice for the ongoing telemedicine project. The new connection is available both at the Hospital of Ngozi and at the “Institute Universitaire des Sciences de la Santé” (IUSS, University Institute of Health Sciences). During working days, houses are connected to Internet through the hospital connection, while in the night and in the weekends they are connected using the IUSS connection.

The IUSS is the headquarter of the Bachelor in Nursing, organized by the University of Ngozi in cooperation with the University of Verona. The University of Verona provides lab and educational materials, and helps in the organization of the courses. Regularly, teachers from the University of Verona go to Ngozi to teach and train the local personnel.

The IUSS features several classrooms and labs, including a computer lab with 28 computers (20 laptops anchored to tables and 8 desktop PCs) allowing students to access both the digital educational material provided by the teachers and Internet. All the computers of the lab are connected to a local server via a LAN. The server runs Debian GNU/ linux, it is located in a different ad-hoc room, and it acts as Internet router, proxy server, firewall, web content filtering, and shared directory. Moreover, the server provides and manages centralized students’ login accounts and home directories. All the PCs in the computer lab, as well as the main server, are powered by UPS (Uninterruptible Power Supplies) units, helping to face sudden voltage changes, too.

4) Overall Evaluation of the Environment: As in the remainder of the country, outside the IUSS and the Hospital in Ngozi a very difficult social situation exists and can be easily perceived. Poverty is widespread everywhere, people are disheartened and disappointed and little inclined to action: rather, people seem to be living “waiting” for something to happen. Actually, this is an extremely challenging environment where to start a new and innovative telemedicine project, given the low confidence ratio for the project success. However, we decided to face such design and deployment task, according to the explicit needs highlighted by the physicians involved in the teaching and clinical activities at IUSS and Ngozi Hospital.

B. Related Work

The literature proposes several papers on telemedicine projects: projects can be classified according to several criteria [1], [3].

Projects can be classified according to their main goal: remote education and e-learning, remote assistance, remote diagnosing, remote monitoring, first-aid care. Typically, projects in developed countries focus on remote monitoring, i.e. taking care of the chronic patient while he/she is at home, and on emergency management, i.e. how to provide the patient with a first aid in case of emergency while he/she is going to be transported to the nearest hospital. In most cases, projects in developing countries [10] focus on remote education and e-learning, i.e. to teach nurses and physicians while staying in the developing countries of origin, and on remote diagnosing, i.e. to help local personnel and physicians on primary health-care and on identifying the pathology affecting the patient [11].

Projects can be classified according to their size and, consequently, economic effort and budget. Developed countries feature more complete and more expensive projects [12], [13], while developing countries - whose GDP is much smaller - have smaller, less performing projects, also affected by a limited budget.

Projects can also be classified according to the coverage of the nation where they are deployed. Nation-wide projects involve many care centers (hospitals, first-aid centers), feature a multi-point-to-multi-point connection, and are generally expandable, so that in the future more centers can be involved in the project: local projects involve a very limited number of center, connections are one-to-one, and few possibilities exist for other centers to enter the project. Developed countries generally consider nation-wide projects, which are then managed and controlled by the respective national health services: developing countries encounter many difficulties in nation-wide projects, and only the biggest developing countries may afford such type of projects.

Finally, projects can be classified according to their stage of maturity and, particularly, to their success rate. More complete projects, especially in developed countries, are managed in a better way, very often reach the full maturity and their success is also monitored [14], [15]. Developing countries encounter many types of difficulties [2], starting from the ICT infrastructure, are more prone to be discontinued, and consequently do not reach full maturity.

Focusing on telemedicine projects in developing countries, major ones have been deployed in China and in India. China, despite its rapidly growing economy, is ranked 144, as of 2007 [16], for the overall health system performance. In China [16] 20% of the resources are available to 900 million rural people, which represent some 70% of the entire Chinese population (as of 2007, no further studies available). Most projects involve a rural hospital, connected to a large hospital. Signals, diagnostic images, and videos are acquired in the rural hospital during a first visit, sent to the large hospital, and then refereed and evaluated by the remote specialist. The current (2014) technological infrastructure has greatly improved the communication quality of the telemedicine projects, and most rural locations are now (2014) covered by a good communication infrastructure. In case of an emergency, immediate hospitalization is also considered, as the patient can be transported to the large hospital. Major encountered difficulties refer to the conflicts of telemedicine with traditional medical culture in China, which is mainly based on face-to-face interaction.

In India the situation [17] features a very big number of rural locations. The 20% of the overall national facilities, mainly managed by inexperienced professionals in rural locations, have to take care of some 770 million citizens. The percentage of GDP devoted to health-care is estimated to be 4.9% (as of 2005), for a life expectancy at birth of 52 years: the technological infrastructure reaches over 65% of the Indian landmass and 80% of its population. The main telemedicine projects are know as *Apollo*, *Otri*, and *Asia Heart Foundation*. All of them mainly involved Indian National locations, only, and focused on major needs from cardiology, emergency, radiology, ophthalmology, and nephrology departments. Signals, diagnostic images and videos are transferred among workstations, reaching some peeks of 750 sessions per month. Major difficulties encountered by the projects are bureaucracy and protectionist policies [17], despite the provided services were free and recipients have been generally satisfied with the projects.

Considering smaller and not nation-wide initiatives, small/very small projects, which consequently feature very low budgets, are not properly considered by the specific literature.

III. Design Choices

As design choices, the first step is that of analysing both the environment and the application domain. Next, tools will be selected.

Due to previous experiences, mainly in educational projects, we were involved in the context of the Hospital and the University of Ngozi, Burundi. Such a scenario helped us since very efficient communications channels were already active and available, without having to build them up from scratch. Furthermore, we were aware about the skills of the local personnel, trained in educational programs shared between the University of Ngozi and the University of Verona.

As application domain, from the early stage of the project we considered a teleconsulting system, which could benefit from the education of the local personnel, delivered in cooperation with our colleagues of the University of Verona, and at the same time could improve the quality of care delivered by the Hospital of Ngozi to local people. In order to gather the proper information about the environment and the major local needs and requirements, our technicians performed some local inspections to the Hospital of Ngozi, producing some reports on their observations: these reports are the starting point of the analysis [18].

Based on the above, we then selected the proper tools, also considering the very limited budget available - thus giving precedence to public domain software and free-ware.

A. Local Inspections and Overall Requirements

The goal of the first local inspection (July 2013) was twofold:

i. to become familiar with the social and the work environment in Ngozi, to better understand the real needs of care of the population where the project is to be deployed, and to foresee the major possible difficulties one could encounter during the project itself;
ii. to gather information about the medical equipment available in the Hospital of Ngozi, so that capturing clinical

data (and images) could be performed properly and correctly.

Major results coming from the first local inspection, and that strongly influenced the project design, may be summarized as follows:

i. healthcare and sanitary conditions all over Burundi are extremely critical, as in the entire Sub-Saharan region. Moreover, rules and recommendations from the East African Community, which Burundi belongs to, must be considered and respected. In fact, respecting the local culture and habits is a key issue for the acceptance of the project and, consequently, for its success;
ii. healthcare professionals lack everywhere, especially in rural regions where the 90% of the entire population is living (Sub-Saharan region). In the average, one physician covers an area with a population of 50,00÷100,000 inhabitants (as a comparison term, in Italy we have one physician every 240 inhabitants [19]) and one nurse covers an area of 10,000÷15,000 inhabitants;
iii. hospitals are run-down, and in most cases they do not have sufficient or sufficiently-educated personnel;
iv. education of personnel is poor. Local people having a chance of education in developed country (Europe or US) prefer not to move back to their original country after completing the education, or if they move back they carry along with them a culture which has no chance of success in the African countries;
v. local schools and universities experience very low budgets, and, if left alone with no cooperation with universities from developed countries, the quality of education remains at a very low-level;
vi. international aids and interventions are baffled by lack of local infrastructures and of local technicians which could take care of the everyday routine and of the continuing use of the innovation brought from outside the country.

Finally, during the first local inspection, some physicians and nurses were identified as preferred-contact persons, setting up a direct communication between the developers in Verona and the users in Ngozi.

After the first local inspection, a second local inspection (July 2014) was held, moving from the results of the previous inspection. The second local inspection aimed at:

i. providing local users with assistance in using the facilities of the computer lab of the university;
ii. delivering some computer systems, discontinued by the Computer Science Department of the University of Verona but still usable even if no longer the "top-performer" ones;
iii. installing a first prototype of the software system for telemedicine and remote consulting, so that physicians of the Hospital of Ngozi could easily share clinical data with their colleagues of the School of Medicine at the University of Verona (Azienda Ospedaliera Universitaria Integrata di Verona);
iv. setting up a brief course on fundamentals of telemedicine and on the software system we deployed. The course has been delivered to the local personnel, as to provide them with the proper skills to efficiently use computer systems and actively cooperate in the project;
v. training the computer technician on how to use the computer system we deployed and on how to support local users in using it;
vi. training the nurses on how to use the ECG machine, so that ECG acquisitions could be performed without the direct intervention of a physician;
vii. training the physicians on how to use the ultrasound system, so that higher quality ultrasound exams could be performed.

B. The Clinical Application Domain

The choice of the clinical application domain, especially for a project targeted to a developing country, has to mainly consider the following aspects: real needs of the assisted population; resource availability, not just in terms of pure amount of money devoted to the project, but also in terms of technological environment (electric power, Internet connection just to mention few of them); skills of the local users, as if no experienced user is found locally, the system will immediately become forgotten as the developers abandon the location; success rate of the project, also in terms of "how long will it remain in use" after the initial enthusiasm and after the developers release the system for the everyday practice.

According to such criteria, and since the Hospital of Ngozi is equipped with some ultrasound (echography) systems and some X-ray systems, the development of a telemedicine system for the diagnosis based on medical images (ultrasound and X-ray) seemed to be a real advantage for the hospital itself. In particular, the initial focus of the project has been on the diagnosis of cardiological pathologies in a paediatric setting. Moreover, no particular additional skill seemed to be fundamental, beyond those already owned or learned after a brief training course by the local personnel.

The adopted solution, thus, was that of a co-management of the Ngozi Hospital: such co-management means that major critical decisions are taken in agreement between the remote center (University of Verona) and the local center (the Ngozi Hospital), thus achieving some immediate advantages for the local population.

Such a solution requires that the local physicians agree on asking an expert second opinion on the most critical cases. Local physicians generally do not hold a specialization degree, and most (if not all) of them are GP (general practitioner): thus, it should be clear that requesting a second opinion does not mean lack of skills or of capabilities in managing critical cases, but rather recognizing the advantages coming from a consultation with other experts.

C. Tool Selection

The main criteria driving the choices when selecting the tools for a telemedicine project concern the open-source or customizability feature, and compliance to existing standards (for files, for information archiving, for information exchange, for interoperability between the programs, just to mention few of them).

Using open-source tools enables the developers to add modules managing peculiarities in the requirements, without having to write the entire application from scratch. Customizability, either via suitable configuration files or via some programming languages or API (Application programming Interface), enables developers to tailor the system to the specific clinical domain and to the requirements from the users, again without having to write the application from scratch.

Compliance to standards and recommendations enables the system to easily import/export data, and also to achieve interoperability among the several modules used within the systems itself. Additionally, other centres - not originally included among those participating to the project for its onset - can later on and easily join the project itself, enriching the possibility of using the telemedicine system. Standard compliance also enables the developers to replace some modules of the system, on condition that the new modules still comply to the standards.

Major standards applicable to the telemedicine project with the Hospital of Ngozi refer to the format for image files. Most relevant references include the ISO 12052:2006 standard, and the DICOM (Digital Imaging and COmmunications in Medicine) format: these standards define criteria to transmit, display, archive, and print out medical information such as X-ray images or other bio-images.

As for the tools which fulfill the above mentioned criteria and comply to the above mentioned standards, we considered:

i. dcm4che [20]: it is a collection of open source applications and utilities written in Java and implementing the DICOM standard [21]. It is web-based, and enables users to archive, search and display DICOM images. It also comprises an HL7 [22] server;
ii. TeleMedicine [23]: it is a collection of open source applications and utilities to stream live contents. It acts as a DICOM server, including VOIP (Voice Over IP) functionalities, live streaming and videoconferencing;
iii. Videolan VLC [24]: it is a public-domain and standalone software to remotely transmit images through the Internet;
iv. EKIGA [25]: it is an open source system for videoconferencing, instant messaging and VOIP. It is interoperable and adheres to the major telephony standards (including SIP an H.323);

However, the above mentioned tools, despite being the most reliable and used ones in their respective fields, have not been used within the project due to some reasons.

In fact, Videolan VLC and EKIGA require a synchronous connection featuring a good bandwidth, and they cannot refer to any content which is stored by a DBMS (DataBase Management System) or by a server: within a telemedicine system, it is advisable that the user simply clicks on the suitable link to access the contents, without having to take care on how to reach the proper resource (file or image or movie) or on how to connect to a server to reach the proper resource. As for dcm4che and TeleMedicine, they are extremely powerful tools in managing DICOM files and this would suggest their adoption within the telemedicine system. Unfortunately, the biomedical instrumentation (ECG, ultrasound, X-ray) deployed at the Hospital of Ngozi does note feature any direct DICOM output, so that the instrumentation could easily transmit the images to the archiving system. Additionally, none of those tools helped in developing an electronic medical record - yet a very simple one with few demographic and clinical data about patients. Thus, as a matter of fact, the tools above revealed themselves to be not appropriate for the specific domain.

Instead, we had to opt for more general purpose tools, which enabled us to develop a domain specific application. In order to do that, we chose Drupal as CMS (Content Management System), Apache as web server, and PostgreSQL as DBMS [26], [27], [28].

IV. System Design and Architecture

The requirements, as gathered by the first local inspection (see Section III-A), and the technical instrumentation available (ECG, ultrasound, X-ray) in the Hospital of Ngozi lead us to develop an ad-hoc system to share patients' data (a very limited set of alphanumerical data, signals, and images) between the local physicians (patient-side ones in Ngozi) and the remote physicians (in Verona).

The system we developed has a web-based interface (by the Apache system) and a content management system (CMS, namely Drupal), running on a linux system. All the information, which can be profitably managed by a DBMS, are managed by PostgreSQL. Such information refer to authorized users, defined taxonomies (e.g., the ICD10 International Classification of Diseases [29] issued by the WHO, and some administrative information concerning place of residence within Burundi for patients), other internal contents, as well as the data traditionally managed by an electronic medical record. Figure 1 depicts the concise entity-relationship diagram of the database managing the electronic medical record.

By the system, the user can easily insert the alphanumerical data of the medical record collecting few essential data about the patients (Figure 2), and then upload to the server the acquired signals and images. Since the locally available instrumentation does not feature any DICOM interface, signals and images are acquired by an external professional scanner starting from ECG printouts and X-ray slides. The external professional scanner we brought to Ngozi saves the images in the Jpeg format: files are then manually uploaded into the system. The ultrasound machine can export images (in Jpeg format) and videos (in AVI format) by USB memory sticks: these files are then manually uploaded into the system, too.

Files from ECG signals or ultrasound and X-ray images are stored within a file-systems based repository, directly managed by Drupal. Since many files can be acquired, the repository

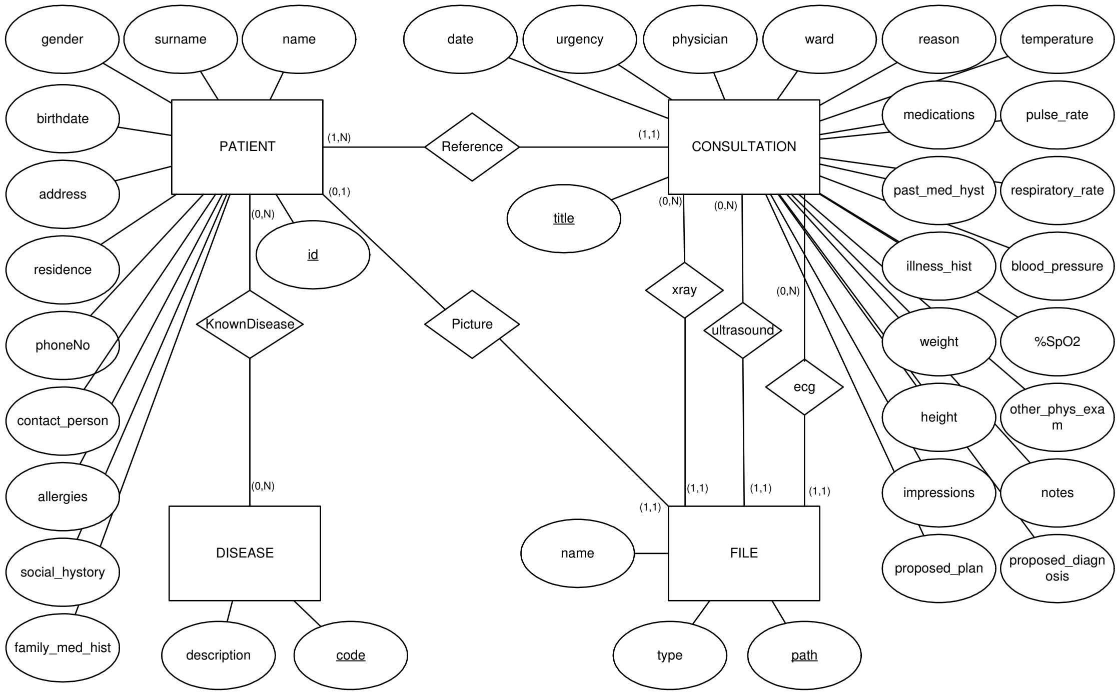

Fig. 1. Entity-relationship diagram of the electronical medical record.

has a tree structure, where files are organized in subdirectories sorted by year, and within the year in subsubdirectories sorted by month: thus, the directory "`2014/September`" includes all the Jpeg files related to examinations performed during September 2014. Such a structure optimizes access to the several files which are collected during the everyday practice. Images are then available to users by the web-based interface, and PostgreSQL stores the complete path and file name of every exam within the repository.

In order to increase the real use of the system, we also implemented a version tailored to mobile devices (smart phones), so that physicians in Ngozi can enter alphanumerical data for new cases or display data about stored cases directly on their mobile phones. In some cases, physicians can take a snapshot of the images by their mobile phones and upload those files to the system: obviously, the quality of images acquired by mobile phones is lower that the quality of the images acquired by the external professional scanner.

Also, within the Drupal system, we integrated a simple workflow management system, which by some triggers helps to manage the requests from Ngozi to Verona. In fact, when a new case in inserted (activities Acquire Patient and Lab Data, Insert Patient Data, Insert Consultation Data of Figure 3) by the users in the Hospital of Ngozi requesting a remote consultation, users at the University of Verona are automatically alerted by an e-mail message (activity Read Consultation of Figure 3), inviting them to take care of the request. Next, when a reply is available (activities Write Result and Wait for Question and Reply) from the remote physicians in Verona, local physicians in Ngozi are automatically alerted by an e-mail message, inviting them to read the reply (activity Read Result) form their remote colleagues, thus completing the process of requesting an expert second opinion. Figure 3 depicts the simple process model describing the activities performed when a new consulting is requested: the graphical notation is BPMN (Business Process Modelling Notation). All the tasks and their synchronization are supported through a suitable connection to the healthcare repositories (DB Ngozi and DB Verona).

Figure 4 reports the complete architecture of the systems. The system in Ngozi is made up by a web server, including Drupal and Apache, and by a PostgreSQL DBMS: the Ngozi server takes care of serving all the requests coming from local users. The system in Verona is a replica of the one in Ngozi, and features an additional chat server (RealChat) which is used for rapid message exchange between the two teams of physicians. Synchronization between the two locations is performed both for the DBMS (by the tool RubyRep [30]), and for the Drupal repository (by the tool Unison [31]).

Archive replication fulfills a twofold requirement. It provides the users with a back-up archive, avoiding loss of information in case of a severe failure in one of the two systems. It also provides the users with an off-line synchronization, which is extremely important since the bandwidth of the connection may require a not negligible amount of time to transmit one image from Ngozi to Verona: thus, after an image has been acquired and stored in Ngozi, it may take several minutes before that image can be seen by the remote physicians in Verona. By the off-line synchronization, physicians in Verona

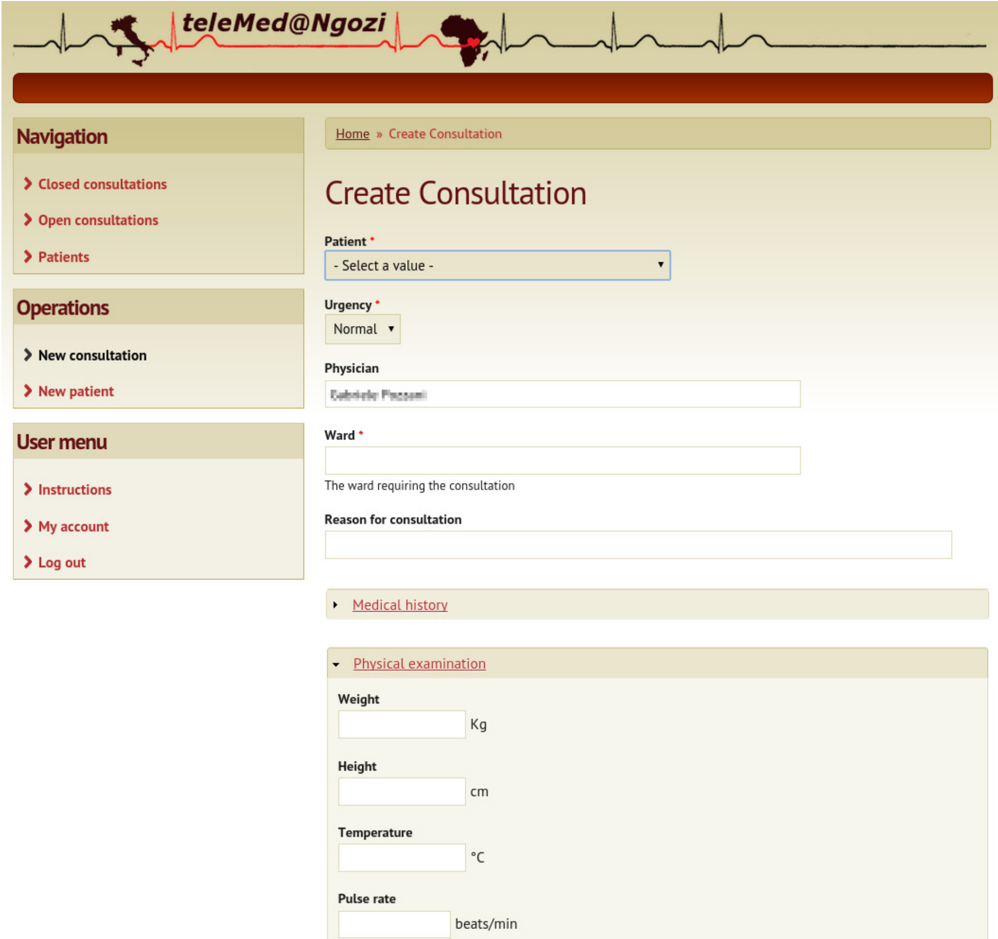

Fig. 2. One screenshot from the essential medical record: very few data are requested.

may refer to the entire archive - as originally stored in Ngozi - without having to download every time all the required images from the remote location: the available bandwidth, which is very small, can thus be successfully exploited for teleconferencing/teleconsulting and simultaneous access.

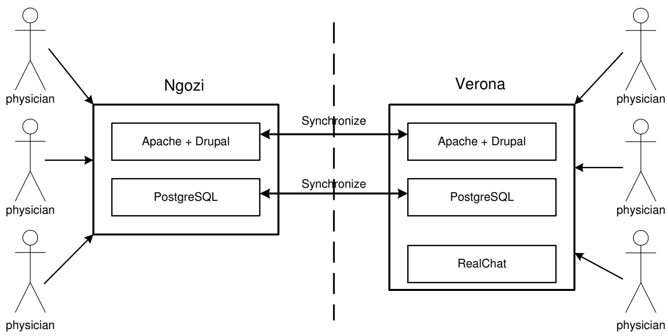

Fig. 4. High level architecture of the system.

V. Local Users' Involvement and First Deployment Tests

When designing a computer system in general, all the good practices suggested by the software engineering techniques must be followed. When designing a telemedicine system, some more good practices must be followed, considering the critical aspects typical of the application domain (e.g., in some situations there is no way of applying an undo mechanism, some situations are irreversible, or some decision must be taken in a short time and with partially available data) and that potential users may be not skilled as needed or as advisable. Furthermore, designing a telemedicine system to a target of a developing country, that is with some more difficulties e.g. coming from the technological or the social environment, is even harder.

The major pitfalls in telemedicine systems, especially those deployed in a developing country, include - but are not limited to:

i. disregarding local habits (both medical as well as cultural and religious ones): introducing some techniques which strongly differ from the local practices or that may result as offending according to the local habits or

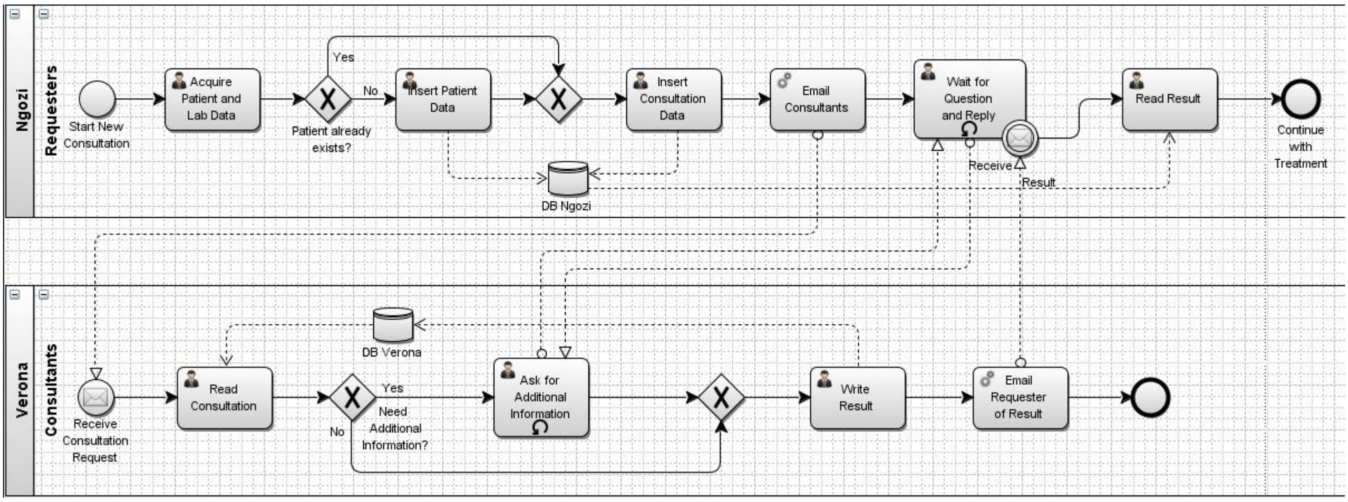

Fig. 3. BPMN graph describing the business process model managing the teleconsulting.

religion, must be absolutely avoided, or the project will fail even before its start;

ii. not providing the users with the proper training in ICT in general and with the specific adopted system: while it is reasonably expected that any physician in a developed country is familiar with using a PC, such a requisite can't be given for sure in a developing country;

iii. abandoning the local users after releasing the system, without providing them with a continual assistance, training and guidance: in fact, the initial enthusiasm may hide some critical aspects, which - after having become evident - may endanger the continuing use of the system.

Thus, involvement of local users is one of the most fundamental steps to be performed. In order to avoid these major pitfalls, we paid particular attention to involve local users, providing them with the proper skills before deploying the system, and then performing a continuous follow up of the system and of its usage in the everyday practice.

For this reason, we trained 20 nurses on how to use better the ECG machine, and 5 physicians on how to use the ultrasound system for performing echocardiographic examinations. Moreover, all of them, have been informed about the provided second opinion system.

The first time, the proposed system has been used during a screening of cardiovascular diseases performed in the first two weeks of August 2014. A radio message has been broadcast to inform the population of Ngozi about the possibility of being visited by Italian cardiologists. About 180 persons have been visited, identifying 25 suspected cases of rheumatic and congenital cardiovascular patients (50% of them were pediatric ones). Data and knowledge about suspected cases have been shared with physicians in Verona for a second opinion. Besides basic information and clinical notes, all shared consultations have ultrasound attachments (images and videos), and some of them have X-Rays and ECGs, too. This screening and consultation process involved two physicians in Ngozi and four physicians in Verona. Some of the consultations confirmed the suspects and identified patients for surgical intervention.

We note that, although the project focused on cardiovascular diseases, the proposed system has been used also to ask for a second opinion about cases of cancer, pneumonia, and laryngomalacia.

VI. Conclusions

In this paper we described a telemedicine system we deployed in the Hospital of Ngozi, Burundi. The system aims at providing local physicians with an expert second opinion on interpreting ECG (electrocardiographic signals) and biomedical images (X-ray and ultrasound images). We designed a suitable system architecture, whose main feature it that of automatically replicating the local archives (Hospital of Ngozi) in the remote location (University of Verona): main advantages of the deployed architecture are those of granting access to data also in case of (partial) failure of the Internet connection, and of enabling off-line remote consultation.

As a new case is detected in Ngozi, acquired signals and biomedical images are immediately stored in the local server and, as soon as the Internet connection provides the proper transmission speed, replicated in Verona. Physicians in Verona can then analyze the data about the new case, and send back to Ngozi comments, suggestions, recommendations, providing local physicians with an expert second opinion. In case a teleconfering/telecosulting is needed, the Internet connection is exploited just for the voice communication between the centers, without having to send signals and images - this could generate a collapse of the Internet connection due to its limited bandwidth.

A. Critical Aspects Encountered

The major critical aspects we encountered refer to a limited bandwidth connection and to the limited number of IP addresses which are statically assigned to the LAN in Ngozi.

As a consequence of such problems, physicians of the Hospital of Ngozi are more and more using their personal mobile phones to share images with their colleagues in Verona via peer-to-peer programs, mainly by WhatsApp, without storing data and images in the computer system. In fact, at the current stage of the project, some 40 cases have been uploaded into the system, mainly during the time when our technicians were staying in Ngozi.

However, the use of this "alternative" communication (peer-to-peer via mobile phones) between the physicians in Ngozi and their colleagues in Verona proves the efficacy of the idea behind the project: we are confident that, as some of the major technical difficulties will be solved, the telemedicine system will reveal all of its advantages, and its use in the everyday practice will start increasing rapidly.

B. Future Directions

Among the future research directions, we plan to increase the number of computer systems which can be simultaneously connected to the LAN in the hospital, adopting a local NAT (Network Address Translator) server. We plan to increase the actual bandwidth, which in same cases does not suffice to grant a reasonable communication channel during teleconferencing/teleconsulting: this can be achieved by adopting an UMTS of LTE connection.

We also plan to extend the application domain to include a wider set of pathologies, and to include some screening campaigns, mainly in the sector of rheumatic and congenital cardiovascular diseases, which are affecting the local population and for which a teleconsulting can produce significant improvements.

Finally, we plan to organize a fellowship which could enable the medical personnel from Ngozi to stay in Verona for some months, attending training courses both in the medical field (electrocardiography, ultrasound, blood saturimetry) and in the technical field (use of the teleconsulting system described by the paper): after the training, the personnel will return back to Ngozi to reinforce the use of the teleconsulting system.

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REFERENCES

[1] World Health Organization, *Telemedicine: opportunities and developments in Member States: report on the second global survey on eHealth*, ser. Global Observatory for eHealth Series, 2. World Health Organization, 2009.

[2] R. Wootton, "Telemedicine and developing countries-successful implementation will require a shared approach," *Journal of Telemedicine & Telecare*, vol. 7, 2001.

[3] A. G. Ekeland, A. Bowes, and S. Flottorp, "Methodologies for assessing telemedicine: A systematic review of reviews," *I. J. Medical Informatics*, vol. 81, no. 1, pp. 1–11, 2012.

[4] Fondazione Pro Africa, "Progetto Ngozi." [Online]. Available: http://www.FondazioneProAfrica.com

[5] Central Intelligence Agency (CIA), "GDP - per capita (PPP), The World Factbook," Available online, July 2013. [Online]. Available: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2004rank.html

[6] International Monetary Fund (IMF), "World Economic Outlook," Available online, April 2013. [Online]. Available: http://www.imf.org/external/pubs/ft/weo/2013/01/weodata/index.aspx

[7] World Bank, "GDP per capita, PPP (current international), World Development Indicators database," Available online, July 2013. [Online]. Available: http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?cid=DEC_SS_WBGDataEmail_EXT

[8] Institut des Statistiques et des Etudes Economiques du Burundi (ISTEEBU), "Annuaire statistique du Burundi 2010," Available online, July 2012. [Online]. Available: http://www.isteebu.bi/images/annuaires/annuaire%202010.pdf

[9] International Telecommunication Union, "Mobile-cellular subscriptions per 100 inhabitants," Available online, June 2013. [Online]. Available: http://www.google.com/publicdata/explore?ds=emi9ik86jcuic_&ctype=l&strail=false&bcs=d&nselm=h&met_y=i911&scale_y=lin&ind_y=false&rdim=country&idim=country:BI:IT&ifdim=country&tstart=650584800000&tend=1344895200000&hl=en_US&dl=en_US&ind=false&icfg

[10] R. Wootton, "The possible use of telemedicine in developing countries," *Journal of Telemedicine and Telecare*, vol. 3, no. 1, pp. 23–26, 1997.

[11] A. Martínez, V. Villarroel, J. Seoane, and F. del Pozo, "Rural telemedicine for primary healthcare in developing countries," *IEEE Technol. Soc. Mag.*, vol. 23, no. 2, pp. 13–22, 2004.

[12] R. S. H. Istepanian, "Telemedicine in the United Kingdom: current status and future prospects," *IEEE Transactions on Information Technology in Biomedicine*, vol. 3, no. 2, pp. 158–159, 1999.

[13] H. Lamminen, V. Sernberg, K. Ruohonen, and R. Roine, "A three-year follow-up of Finnish telemedicine programs," *IEEE Transactions on Information Technology in Biomedicine*, vol. 5, no. 2, pp. 174–177, 2001.

[14] R. Wootton, A. Geissbuhler, K. Jethwani, C. Kovarik, D. A. Person, A. Vladzymyrskyy, P. Zanaboni, and M. Zolfo, "Comparative performance of seven long-running telemedicine networks delivering humanitarian services," *Journal of telemedicine and telecare*, vol. 18, no. 6, pp. 305–311, 2012.

[15] K. Bahaadinbeigy, K. Yogesan, and R. Wootton, "A survey of the state of telemedicine in Western Australia," *Journal of telemedicine and telecare*, vol. 16, no. 4, pp. 176–180, 2010.

[16] Y. Xue and H. Liang, "Analysis of telemedicine diffusion: The case of China," *IEEE Transactions on Information Technology in Biomedicine*, vol. 11, no. 2, pp. 231–233, 2007.

[17] A. Pal, V. W. A. Mbarika, F. C. Payton, P. Datta, and S. McCoy, "Telemedicine diffusion in a developing country: The case of India (March 2004)," *IEEE Transactions on Information Technology in Biomedicine*, vol. 9, no. 1, pp. 59–65, 2005.

[18] G. Pozzani, "The Burundi project at the University of Verona." [Online]. Available: http://profs.sci.univr.it/~pozzani/burundi.php

[19] Central Intelligence Agency (CIA), "The World Factbook." [Online]. Available: https://www.cia.gov/library/publications/the-world-factbook/

[20] G. Zeilinger, "dcm4che." [Online]. Available: http://www.dcm4che.org/

[21] DICOM Standards Committee, "Iso standard 12052:2006 "health informatics – digital imaging and communication in medicine (dicom) including workflow and data management"."

[22] Health Level Seven, "HL7 standard." [Online]. Available: http://www.hl7.org/

[23] "TeleMedicine." [Online]. Available: http://sourceforge.net/projects/teleconf/

[24] VideoLAN organization, "VLC." [Online]. Available: http://www.videolan.org/vlc/

[25] D. Sandras, "EKIGA." [Online]. Available: http://www.ekiga.org/

[26] D. Buytaert and D. Community, "Drupal." [Online]. Available: https://www.drupal.org/

[27] The Apache Software Foundation, "Apache HTTP Server." [Online]. Available: http://www.apache.org

[28] PostgreSQL Global Development Group, "PostgreSQL." [Online]. Available: http://www.postgresql.org

[29] "International classification of diseases: Icd-10 version 2015." [Online]. Available: http://apps.who.int/classifications/icd10/browse/2015/en

[30] A. Lehmann, "rubyrep." [Online]. Available: http://www.rubyrep.org/

[31] B. C. Pierce, "Unison." [Online]. Available: http://www.cis.upenn.edu/~bcpierce/unison/