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UBIHEALTH: A UBIQUITOUS COLLABORATIVE SYSTEM TO SUPPORT TELEMEDICINE

Felipe dos Santos and Cristiano André da Costa
Programa de Pós-Graduação em Computação Aplicada (PIPCA)
Universidade do Vale do Rio dos Sinos (UNISINOS)

ABSTRACT

Brazil lacks doctors to achieve a satisfactory provision of health services in all regions. Trying to mitigate this issue, this article describes a model of a telemedicine system named UbiHealth. The system is designed to support adoption of telemedicine, primarily seeking to improve the quality of diseases diagnosis in Brazil through collaboration between medicine professionals. The model is based on a client/server structure where clients are mobile devices that consider different forms of usability in order to integrate the system to the daily actions and behavior of professional in the most natural way possible. Besides improving the diagnosis of diseases the system also intend to bring benefits reducing cost and reducing the need from the people involved to travel. We also present a developed prototype for multiple mobile platforms. We evaluated UbiHealth by assessing usability, effectiveness, efficiency and satisfaction of its users. The results were encouraging and show the potential benefits of deploying UbiHealth in real medical environments.

KEYWORDS

Telemedicine, Ubiquitous computing, Mobile computing, Collaborative software.

1. INTRODUCTION

The UbiHealth system is designed to enhance the medical services in Brazil, more specifically the quality of diagnosis. Often the diagnosis is made without the necessary attention from an expert because of the distance limitation, which is a critical factor in Brazil by its vast territory. Here will be shown as alternative a model of a system that combines the use of mobile devices and collaboration tools. Combining these elements is expected to not only improve the quality of the diagnosis provided but also offer a user-friendly system that can be used in the most natural way by its users.

According to World Health Organization (WHO), in 2008 Brazil had 1,76 physicians out of 1000 inhabitants, compared to 3,73 in Uruguay, 6,57 in Cuba and 2,42 in United States. Detailing this index by federative unit of Brazil is noticed that there is a great disparity between the different states as exposed in the research Medical Demography in Brazil (Demografia Médica no Brasil) held in 2011 by Conselho Federal de Medicina (CFM). This same research provides the information that, the difference between resident of country town of a poor state and resident of a southern or Southeast capital is, at lease, 4 times.

Brazil is the fifth largest country in area, with a total area of more than 8 million square kilometers and with difficulties to achieve satisfactory coverage of health services. This makes the country a good candidate for the study of alternatives to increase health service coverage through the use of telemedicine.

When designing a telemedicine system, we must consider the aspects related to the practice of medicine and the challenges in creating such a system so as not to compromise the service provided by the physician. Aiming to avoid these problems UbiHealth use mobile devices like smartphones and tablets to support collaboration among physicians during the exercise of their activities. To address these questions is also necessary to know and apply concepts of ubiquitous computing, where according to Weiser (1991) the technology must be integrated into the daily life of its users as to become invisible. Taking the premise of using mobile devices and technologies they offer, combined with the concepts of ubiquitous computing, UbiHealth is designed to allow interactions between users and the system as naturally as possible, minimizing the boundaries that may, by any chance, difficult its adoption.

The main goal of this work is to develop a collaborative system to support the adoption of telemedicine by using mobile devices to provide a ubiquitous experience to its user, in other words, a system that can be used by professionals to integrate into their actions and behavior of day-to-day in the most natural way possible. The main scientific contribution was to state the necessity of an Ubiquitous Collaborative System to Support Telemedicine that is able to enhance the coverage of the provision of health services and prove that its possible to build it, using cloud computing, mobile devices and filling security requirements.

The article is organized in six sections. Section 2 presents the background concepts employed in UbiHealth. The proposed model is presented in section 3. Subsequently, in section 4, we cover the UbiHealth prototype implementation. Evaluation and results are discussed in section 5. And finally, in section 6, we conclude the work with some remarks and the description of future works.

2. BACKGROUND

The UbiHealth project use different concepts to achieve its objectives. The main concepts used are Telemedicine, Collaborative Systems, Ubiquitous Computing and Context-Aware Computing. All of them are described in this section.

The American Telemedicine Association (ATA) defines telemedicine as the use of medical information exchanged between different locations via electronic communications to improve the health status of patients. ATA (2012) also states that a system of referral services specialists typically involves a specialist assisting a general practitioner to provide a diagnosis. This may involve a patient seeing a specialist live, remotely or via transmission of diagnostic images and/or video along with patient data to a specialist to check it later.

The aid provided by the specialist to the general practitioner leads to Collaborative Systems. The oldest definition of Collaborative Systems, also known as groupware defines them as "Intentional processes for groups plus software to support them" Johnson-Lenz and Johnson-Lenz (1990). Examples of Collaborative Systems presented by Jalbani et al. (2012) are email, calendar, chat, wiki and bookmarks. Bardram (2003) reports the existence of challenges in the use of systems in contemporary computers that makes them unsuitable for clinical work. It is for example difficult to operate a keyboard and mouse during the operation of a patient. Research involving ubiquitous computing provide a range of new technological and conceptual possibilities, which allow us to move the support of clinical informatics closer to the clinical setting working.

Ubiquitous computing is a term coined by Weiser (1991). He starts the description of the term as “The most profound technologies are those that disappear. They are interwoven into the fabric of everyday life until they are indistinguishable from it.” and in another passage of the same article, Weiser complements “So we are trying to conceive a new way of thinking about computers in the world, one that takes into account the natural human environment and allows the computers themselves disappear.”

A related term widely and often used together is Mobile Computing. Zimmerman (1999) reports that Mobile Computing is the term used to describe computing devices that usually interact with a central information system, while lying outside the fixed workplace. Mobile computing technologies enable its user to: create, access, process, store and communicate information without being restricted to a single place and enable context-aware computing applications.

The first work to cite "Context-Aware Computing", is from Shilit and Theimer (1994), and describes context as: local, people identity and nearby objects, and changes to those objects. Dey (2011) on the other hand reports that the description of Shilit and Theimer is very specific and sets context as: “Context is any information that can be used to characterize a situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between the user and the application, including the user himself and the application itself.” At the conclusion of Dey work he mention that in the near future the service will combine different types of context information to give the user an experience that will perfectly suit their context at any given time.

3. PROPOSED MODEL

This section presents the model for supporting the adoption of telemedicine. It is focused on help obtaining a second opinion using synchronous and asynchronous collaborative tools, with the help of medical images. The main advantages of the proposed model are the use of collaboration through the use of cloud computing, the use of the DICOM standard for the files format, the interactions through mobile devices that have capabilities like gestures and voice as proposed by Bardram (2003), and the use of sensitivity to user context. The system was named UbiHealth.

The functional requirements are: Users maintenance; Patients maintenance; Medical records maintenance; List patient's medical records; List active cases; Share case with another physician; Collaboration through messages; Collaboration through video; Selection of level of patient privacy; and Cases maintenance.

The non-functional requirements are: Scalability and reliability through Cloud Computing; Interoperability using web server; Interoperability using DICOM standard; Interoperability using REST web services; Portability through mobile devices clients; Security using digital certificates; Security through passwords; Usability adjusting to context; Usability through voice commands; and Usability using gesture commands.

UbiHealth model is designed based on the concept of distributed system with client-server architecture. Client applications are installed on mobile devices such as tablets and smartphones that communicate over web services with server applications, which will be in accordance with the cloud computing concept. It means that servers share memory, storage and processing to ensure that the service is stable and can be used by a large number of concurrent users without performance degradation. Figure 1 shows a block diagram where the main components of the systems are presented and classified as UbiHealth components or external components. You can also view some elements of the communication between the layers. Where clients communicate with servers using the REST architecture over HTTPS protocol.

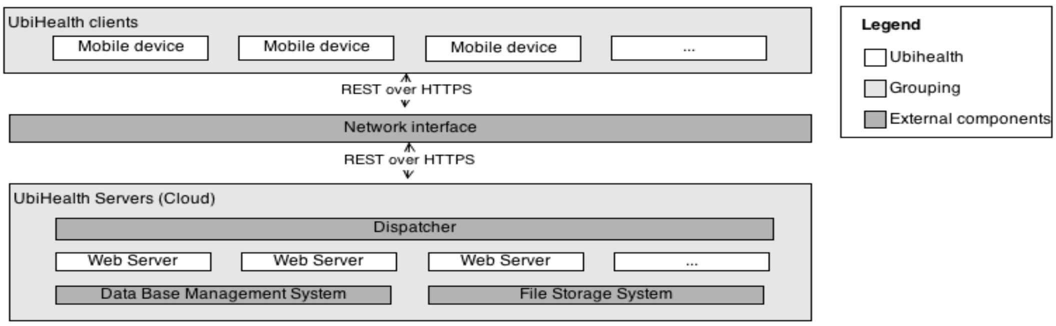

Figure 1. UbiHealth blocks diagram

4. IMPLEMENTATION

We developed a prototype comprising some of the requirements designed in the UbiHealth model. The main steps for the implementation were the requirements selection, followed by the technology selection, subsequently the design is explained and finally the development of the prototype.

Not all the requirements were selected for prototype implementation. The criteria for requirements selection was based on time available for work completion and upon the value proposition of the UbiHealth system, so the first system version can have valuable features that enables the evaluation process. The requirements not implemented in this version are: Collaboration through messages; Collaboration through video; Selection of level of patient privacy; Interoperability using DICOM standard; Usability adjusting to context; Usability through voice commands; and Usability using gesture commands.

Two main technologies were needed for the project, the Server and the Client technologies. For the client the main requirement was to be a mobile platform. Some different platforms were evaluated, like Android, Apache Cordova, iOS and Windows Phone. After evaluation, the chosen technology was the Apache Cordova. The main aspects for the decision are the possibility to compile the same source code for different platforms and also our previous knowledge in web development. The second most important technology to be chosen is the server side technologies that can enable the requirements to be developed on time and with the expected quality. In Cloud Computing, there are eight different types of providers as stated by Sareen (2013). Two of them, Storage as a service (STaaS) and Backend as a service (BaaS) are especially important for UbiHealth implementation.

STaaS is a business model in which a large service provider rents space in their storage infrastructure on a subscription basis. Storage as a Service is often used to solve offsite backup challenges. Critics of storage as a service point to the large amount of network bandwidth required conducting their storage utilizing an internet-based service. Sareen (2013)

BaaS is a model for providing web and mobile app developers with a way to link their applications to backend cloud storage while also providing features such as user management, push notifications, and integration with social networking services. These services are provided via the use of custom software development kits (SDKs) and application programming interfaces (APIs). Sareen (2013)

Most of BaaS solutions has the required features to attend the Ubihealth requirements, like Digital Certificates to ensure security in the communication and REST web services to ensure interoperability among different platforms. The chosen solution is called Stackmob, it was selected both for having a free tier version that fits the UbiHealth needs and a JavaScript SDK, that enable close integration with Cordova platform. To store files attached to the medical records a complementary solution of STaaS is necessary, to supply this need the Amazon S3 service was selected. The main reasons for this choice are because it has a free tier that fits into the UbiHealth needs and also because Stackmob has a close integration with it. Table 1 shows a summary about these and other technologies used in the prototype creation.

Table 1. Technology selected for UbiHealth implementation

Technology/tool necessary	Description of use	Selected tool and it's version	Reason
Diagrams	Create UML diagrams.	draw.io	Free and easy to use.
Mockups	Create mockups for the UbiHealth screens.	Balsamiq Mockups 2.2.11	Easy of use and can deliver good mockups for the project.
Mobile development platform	The mobile platform for which the Ubi-Health project will be implemented.	Apache Cordova 2.7.0	Free and can be compiled for the main mobile platforms in the market.
Backend as a service	Cloud Computing service that easily provide REST web services.	Stackmob	Free tier that fits the project needs and compliant to project requirements.
Storage as a service	Reliable and Cloud Computing compliant file storage	Amazon S3	Free tier that fits the project needs and easy integration to Stackmob.

The first step after choosing the necessary technology is to build the data store schema. Stackmob is different from most of database management systems, it has: standard fields in all schemas; access control defined directly into the schema; foreign key fields can receive a list of values; a standard schema defined for users; web service operations automatically created based upon the schemas. The schemas created for the prototype are shown in Figure 2. In the case_records there is a field called file_path, this fields is a link for the Amazon S3 service, so every binary data stored or retrieved from this field, in fact is stored in the Amazon S3 storage service.

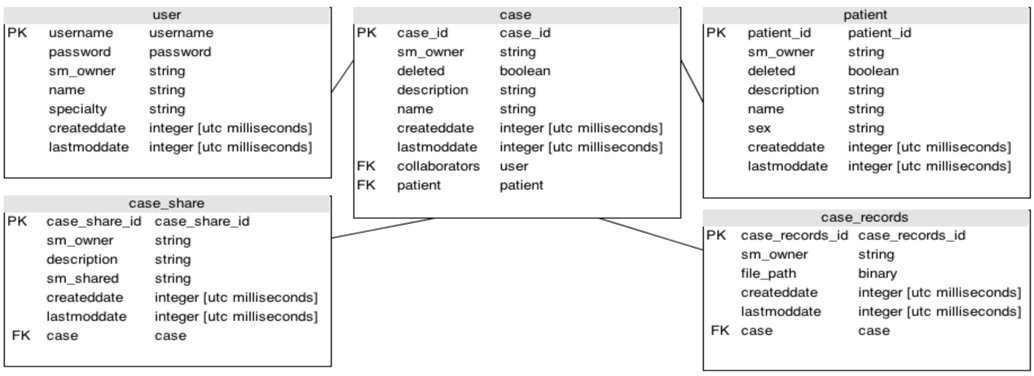

Figure 2. Stackmob UbiHealth schemas

Some screen mockups were developed using the Balsamiq Mockups tool. The mockups were a very valuable resource to validate the user experience planned for the prototype to be as natural and as intuitive as possible. Once the development itself started was easy to develop the screens based on the mockups. One problem related the layout development was the necessity of adjusting it for the different devices with different resolutions. We had three devices available to test the prototype: tablet Motorola Xoom running Android 4.1; Nokia Lumia 710 running Windows Phone 7.8; and Samsung Galaxy 5 running Android 2.2.

Apache Cordova development is based on web development using HTML, CSS and JavaScript. Cordova enable calls to the mobile operational system features like camera, notification, storage and others. Like in web development, is necessary to take into account the differences from platform standard browsers. Develop for different devices was quite easy at the beginning, but the complexity got higher once some differences from the Android and Windows Phone browsers raised and some libraries had different behaviors. In the end the prototype is only fully operational for Android devices, both for the Motorola and the Samsung devices. The Windows Phone device also runs the application, but it lacks adjustments to be fully operational. The final prototype implementation can be seen in Figure 3 running on Motorola Xoom device.

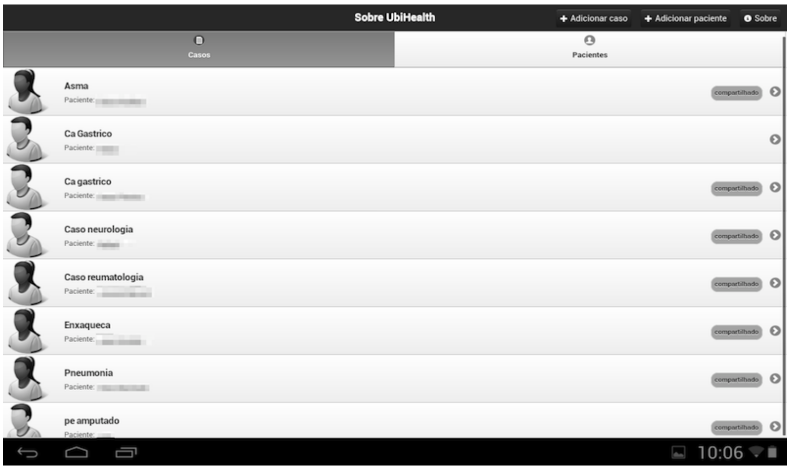

Figure 3. UbiHealth main screen on Motorola Xoom Android tablet

5. EVALUATION AND RESULTS

Since the development of mobile computing, and the advent of mobile applications, the usability evaluation has been employed in the assessment of mobile applications (Biel et al. 2010). According to ISO 9241-11, usability is defined as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” (International Standard Organization, 1998). Following this concept, we employed the framework proposed by Zhang and Adipat (2005) to evaluate the three most important usability attributes (according to ISO 9241-11 definition): Effectiveness is the comparison of user performance with a predefined level; Efficiency is the time that user needs to complete a task; Satisfaction is the attitude of users toward applications after using them.

We were able to perform the prototype evaluation with help of seven pathology specialists, who volunteered to help on the research. The volunteers were 39 years old on average, being 65 the oldest and 32 the youngest. Their experience acting as physicians was 10 years on average, 41 for the most experienced and 4 years for the less experienced. We defined the evaluation protocol based on Kenteris et al. (2009) and carried out a field study using the Android tablet to measure the three attributes: effectiveness, efficiency and satisfaction. We defined a set of four tasks that were assigned to the users. First, we explained the purpose of the application and its main features. Then we asked the users to complete proposed tasks twice. We timed the execution of each task and kept a record of completed ones. Finally, we asked users to answer a survey.

The results of the first quantitative test are summarized in Figure 4. The graph shows the effectiveness (in percent) for completing each task. In fact, all seven users could complete the four proposed tasks. This result indicates that UbiHealth was very effective, because users could complete the four tasks proposed twice.

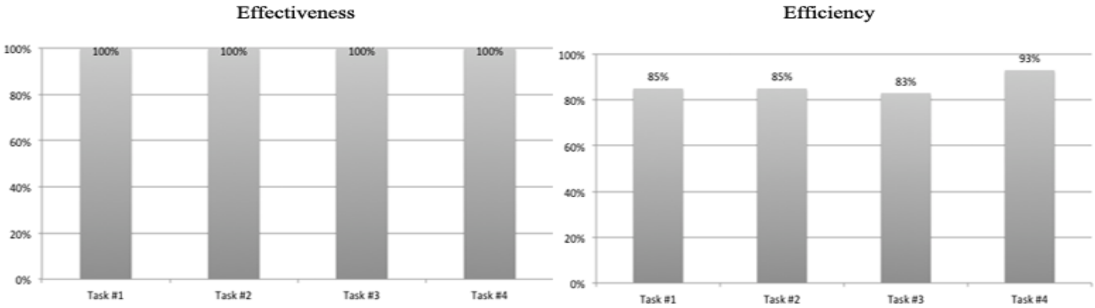

Figure 4. Effectiveness and efficiency of users in completing tasks

The Figure 4 also shows the average efficiency in percent. Each column consists of the average time needed for users to complete each task twice, compared to a gold standard. Analyzing the results is possible to observe that no user got efficiency bellow 80%, which is a good result. The fourth task obtained 93% of average efficiency, the higher efficiency of all four tasks. The golden standard for it was 45 seconds, which means a deviation of approximately 3 seconds. Both Task #1 and Task #2 had average efficiency of 85%. The gold standard was respectively 80 seconds and 60 seconds and the deviation was approximately 12 seconds and 9 seconds. Since these tasks involves text input, the time taken to complete it depends upon variables as user type speed and size of entered data. For example, the story created for the fictitious patient. Task #3 had the lowest efficiency, with a deviation of approximately 9 seconds and a golden standard of 55 seconds. The quite different times for completing this task can be also explained by the dependency of variables like user type speed and size of the data entered for the fictitious case. What makes it a bit different from Task #1 and Task #2 is that for case creation there is more room for creativity on data provided.

Since we asked for users to execute twice each task, we also measured learnability, i.e. which was the gain in terms of time elapsed comparing the mean time for executing each task for the first and second time. The results were summarized in Table 2. The table shows the mean time the users had to execute each task, each time and also the learnability. In Table 2, the Average Efficiency is shown in the format "hours:minutes:seconds". We obtained an average learnability of 76%, meaning that, in average, the second time the users executed the four tasks they had a gain of time of 24%.

Table 2. Tasks proposed and users learnability in its completion

Task	Description	Average Efficiency 1st Time	Average Efficiency 2nd Time	Learnability
Task #1	Create a user and login in the system.	00:01:41	00:01:22	81.2%
Task #2	Create a new patient.	00:01:26	00:00:51	59.3%
Task #3	Create a new case for the previously created patient.	00:01:10	00:00:58	82.9%
Task #4	Comment the created case and share with another doctor.	00:00:52	00:00:43	82.7%

To evaluate satisfaction, the qualitative aspect, we applied a survey to users after completing of the proposed tasks. This evaluation followed the Technology Acceptance Model (TAM) proposed by Davis (1989) and extended by Yoon and Kim (2007), using a Likert scale (Likert, 1932). According to Davis (1989), studies show that among the various factors that people consider more important to accept or reject an application, the perception of utility, i.e. the degree that the user evaluates the application can improve their experience, is the most important variable to consider. The second most important variable is called easy of use, which is defined as the degree to which a person believes that the use of a system is free from stress. This variable complements the first, because according to researches just the application is not enough to be useful, because the benefits of applying must overcome its effort to use (Davis, 1989).

For each factor proposed by the TAM methodology we defined five statements to which the user could choose among 5 options (strong disagree, partially disagree, indifferent, partially agree and strongly agree). We also leave an open question for general comments and suggestions. The assessment of Easy of Use is detailed in Table 3 and summarized in Figure 5. The results show that our model had a good acceptance among users. Nobody chose the disagree options. Besides, 74.3% of users strongly agreed with the proposed statements. We obtained the better result in statement two, regarding the overall app easy of use.

Table 3. Results for Easy of Use Evaluation

Statements	Strongly agree	Partially agree	Indifferent	Partially disagree	Strongly disagree
1. The app is easy to understand	71,4% (5)	28,6% (2)	0,0% (0)	0,0% (0)	0,0% (0)
2. The app is easy to use	85,7% (6)	14,3% (1)	0,0% (0)	0,0% (0)	0,0% (0)
3. With little effort I can find information	71,4% (5)	28,6% (2)	0,0% (0)	0,0% (0)	0,0% (0)
4. With little effort can add information	71,4% (5)	28,6% (2)	0,0% (0)	0,0% (0)	0,0% (0)
5. The features are clear and objective	71,4% (5)	28,6% (2)	0,0% (0)	0,0% (0)	0,0% (0)
General average	**74,3%**	**25,7%**	**0,0% (0)**	**0,0% (0)**	**0,0% (0)**

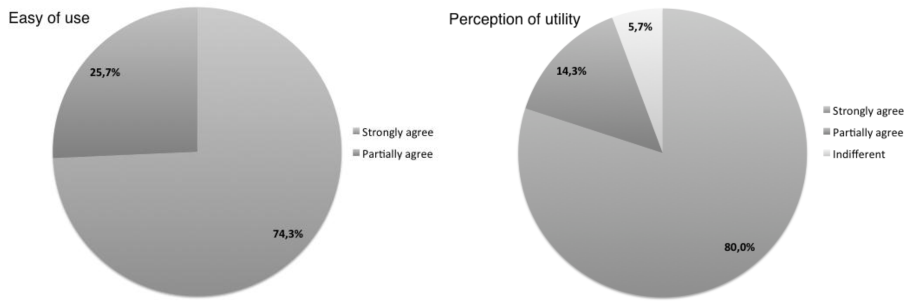

Figure 5. General results for Easy of Use and Perception of Utility Evaluations

The evaluation regarding Perception of Utility is presented in Table 4, and a graph summarizing the general results is presented in Figure 5. Analyzing the results we can see that we had good results also in the perception of utility aspect, although a little bit more spread than the previous evaluation. In this assessment, we had two responses in the indifferent option, both for the app relevancy and the features relevancy. We also had a higher general average in the Strongly agree option (80%). In general, both quantitative and qualitative evaluations of usability were encouraging and showed good results. The rates obtained in the experiments indicate that UbiHealth is a model technologically accepted by this group of users.

Table 4. Results for Perception of Utility Evaluation

Statements	Strongly agree	Partially agree	Indifferent	Partially disagree	Strongly disagree
1. The app is relevant	85,7% (6)	0,0% (0)	14,3% (1)	0,0% (0)	0,0% (0)
2. The app features are relevant	85,7% (6)	0,0% (0)	14,3% (1)	0,0% (0)	0,0% (0)
3. The app facilitates the storage of exams	71,4% (5)	28,6% (2)	0,0% (0)	0,0% (0)	0,0% (0)
4. The app facilitates the sharing of exams	85,7% (6)	14,3% (1)	0,0% (0)	0,0% (0)	0,0% (0)
5. I would use the app if it had access	71,4% (5)	28,6% (2)	0,0% (0)	0,0% (0)	0,0% (0)
General average	**80%**	**14,3%**	**5,7%**	**0,0% (0)**	**0,0% (0)**

6. CONCLUSION

The mobile devices brought with it the possibility to create targeted applications that can take advantage of sensors and other device features like camera and device storage to provide a great experience to the user. To provide the best experience, applications need, among other things, be simple, secure, collaborative and context aware. Taking this into consideration and also the fact that Brazil has a poor coverage of medical services we presented in this work a ubiquitous collaborative system model to support telemedicine, named UbiHealth. The system was mainly designed to improve quality of diagnosis in Brazil.

We developed a prototype that enables the medical professionals to share relevant information and exams from a patient, in order to ask for a second opinion for a more accurate diagnosis. The prototype was created using the Apache Cordova API, what allowed us to create an application that can run on different mobile platforms. Volunteer medical professionals evaluated the prototype. The usability evaluation shows that

UbiHealth prototype had a good acceptance. The effectiveness was 100% for executing the four proposed tasks to be performed in the system. We got above 80% in efficiency percentages, what is a great result. Learnability was also good, with an average of about 76%. Regarding satisfaction we applied the Technology Acceptance Model and obtained encouraging results regarding Easy of Use and Perception of Utility.

As future work is intended to cover the requirements designed in the model but not covered yet. These, are highly required to provide a secure, standardized and context-aware telemedicine system. Finally, is planned the evaluation of connecting the UbiHealth system to medical devices to extract exams information directly from the device to the system and make them available at the mobile device.

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