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Development of Remote Monitoring System for Biomedical Equipment

Abstract

Introduction: Videolaparoscopy is an effective technique to access the body cavities. This technique maintains a minimal invasive impact in relation to other surgical procedures. However, in order to accomplish this technique it is necessary to have trained health professionals and an appropriate, robust set of equipment. The objective of this article is to present and describe a remote monitoring system which was developed to monitor and assist precision biomedical equipment, such as the ones used for videolaparoscopy. This monitoring system, VERA, implements a collaborative methodology between health professionals and equipment maintenance professionals. The system was designed using the 3C model to provide the collaborative characteristics. Moreover, the development and implementation used web technologies. Throughout this process, modeling of the VERA system included conceptual and technical methods such as wireframes, site map and user interaction modeling. The VERA system allowed a collaborative work environment for the technical assistance team (for maintenance purposes) and the health professional responsible for the videolaparoscopy. The steps developed so far reveal that the system developed through the 3C model contributes to the creation of a collaborative environment in the remote monitoring of videolaparoscopic medical equipment. This, in turn, allows the technical assistance team to carry out diagnostic and maintenance with celerity, making it possible to ensure precise and efficient procedures in the Brazilian Unified Health System.

Keywords: Remote Monitoring; Videolaparoscopy; 3C model; Biomedical Equipment; VERA

Introduction

In Brazil, it is the duty of the State to guarantee healthcare as a fundamental right through strategic public policies. To that end, the Unified Healthcare System (SUS in portuguese) has the resources to maintain an infrastructure that is able to promote and protect the health of its people [1,2]. However, in order to achieve these goals and provide a comprehensive care to all, especially in advanced technology procedures, SUS is still striving to introduce new and efficient technologies in the realm of therapeutic and diagnostic interventions [3,4]. As in the open calls for videolaparoscopy, which began in 2014, and have been extended to the present day, there is an emphasis and interest on the possibilities to bring about procedures capable of diagnosing and treating its patients through less invasive techniques [5]. Videolaparoscopy is performed by accessing the pelvic-abdominal cavity through the insertion of components, such as a mini-camera and a cold light source, allowing internal organs to be observed on a monitor [6,7]. This allows diagnostics and surgical procedures, such as bariatric surgeries (recently included in the SUS repertoire of procedures) to be performed. However, the success of such procedures directly correlate with the expertise of the professional and healthcare team involved, further placing the preventive maintenance of the videolaparoscopy equipment indispensable [8]. Therefore, new initiatives to supply these requirements aim to integrate operational and managerial models that provide monitoring information on the performance of the equipment used for the therapeutic and diagnostic procedures in SUS. These include videolaparoscopes [9,10]. Thence, the aim of this article is to present and describe a remote monitoring system called VERA, whose purpose is to monitor the performance of precision biomedical equipment used during videolaparoscopic techniques, through a collaborative methodology between health professionals and professionals focused in the maintenance of the equipment, within SUS.

Methods and Tools

The presentation of the methods elaborates on the development of a monitoring system for biomedical equipment of high precision (VERA) in the context of videolaparoscopy procedure. The main advantage of this system is to allow the remote technical diagnosis of the equipment involved.
A Proposition for a remote monitoring system

Figure 1 illustrates the panoramic architecture of the VERA system. The latter is composed of the videolaparoscopy, concentrator equipment, and web information center. While the camera, light source, recorder and insufflator are videolaparoscopy equipment that will be monitored remotely. The concentrator is the device that collects the information of the functional parameters and alerts the equipment. This information is sent, via TCP/IP, to the information center, a Web server that centralizes the data. In addition to the medical device and equipment information, such as videolaparoscope, this information center gathers information from users and customers. It is important to clarify that the information gathered in the database of the monitoring system harnesses data from two types of users: the first coming directly from the machines and equipment being utilized, and the second being the data that is inserted from the technical staff using the equipment [11]. In order for the VERA system to be fully utilized, it is indispensable to have access to information from users and technicians. This was possible through the collaborative systems strategies implemented, such as the 3C model, which was crucial to gather elements such as user interface and interaction real estate and information exchange. Therefore, the 3C model enabled the definition, classification and spatial distribution of the interface pertaining to the collaborative tools used. Consequently, this allowed users to communicate with one another, creating a technical support and user friendly cooperation that ensures a better work environment for these procedures [12]. The information entered and stored are available for access to the electronic database on the Web. For management of information, variables and characteristics of the monitored systems, MVC (Model-View-Controller) was used. As shown in Figure 2, the system is structured in three elements that, despite interacting, can change independently. The model manages the system data and associated operations on that data. The view component defines and manages how the data is presented to the user. Finally, the controller manages user interaction (for example, typing) and transfers those interactions to the view and template [13].

To present an overview of the implementation, Table 1 summarizes the activities of the WebE framework which describes how the tasks and methods for generating work products that contribute to the development of the collaborative system were performed [14]. Communication enables developers and system stakeholders to understand the problem before beginning any procedures for resolution. This is done in order to ensure that the solution to the problem meets the needs of the user. Table 2 summarizes the functionalities and tasks that the user will execute, defined and classified according to the collaborative methodology of system development. The coordination module has information management capabilities for hospitals, medical equipment and system users. This is in addition to system help functionality, which includes videos-tutorials and FAQs (Frequently Asked Question).

The cooperation module offers the shared spaces both for the monitoring of the functional parameters and the current state of the biomedical equipment, as well as for monitoring the alerts of the same. This module also allows the generation of histories and reports of these parameters and alerts. Finally, the communication module allows both synchronous (textual instant messaging) and asynchronous (contact form) communication. Users who can access the system are members of the work team of the technical assistance company and the health team responsible for the procedure or diagnosis. In the elicitation that involves the categorization of users, the definition of functional requirements and creation of user interactions are done according to responsibilities, knowledge and roles, where the latter defines permissions and restrictions of access to the system. Functional requirements set the behavior of the system. Table 2 shows the functional requirements of the VERA system, which explicitly define the functionalities and services. Starting from the functional requirements are constructed the use cases of the system.
### Table 1: Summary of the Elements Pertaining to the Framework WebE.

| Activities       | Tasks                                      | Method                          | Work Tools                                       |
|------------------|--------------------------------------------|---------------------------------|--------------------------------------------------|
| Formulation      | Formulate the problem of work              | Exploratory research            | System and specifications for Users              |
| Elicitation      | Define user categories                     | User list analysis              | User categories                                  |
|                  | Get functional requirements and system content | Analysis of system requirements system content | Functional requirements of system content       |
|                  | User Interaction schemes                   | User cases                      | Use cases                                        |
| Planning         | Carry out a risk analysis                  | Risk table and contingency plan | System Risks and Contingency Plan                |
|                  | Calendar and planning                      | Scrum                           | Planning development strategies and activities   |
| Analysis Modeling| Realize the interaction model              | Use Case Diagrams               | System use case diagrams                         |
|                  | Make the content template                  | Class Diagrams UML              | System Class Diagrams                            |
| Modeling         | Perform technical design                   | Block diagram                   | Conceptual and technical architecture of the system |
|                  | Carry out information design               | Carry out information design    | System Information Architecture                  |
|                  | Perform interaction design                 | Layout of interfaces and navigation mechanisms | Structure, organization and aesthetics of the system user interfaces |
| Construction     | Select, encode, create, integrate, and refactor components |                                   | System developed                                 |
|                  | Evaluation                                 | Unit Testing                    | System suitable for use                          |
| Implementation   | Create software packets                    | Packed Software                 | System Up and running                            |

### Table 2: Functional Requirements for the VERA System.

#### Management Module

1. The system shall provide technicians and customers with system access tools that enable:

2. Log on to the system by using user credentials;

3. Quit user session.

4. The system should provide technicians with tools that allow the management of: customers, equipment of their hospital network, users of the technical assistance company and the client.

5. The system shall offer to technicians and clients, navigational monitoring by the system.

6. The system should provide the technicians and clients with the help tools, which includes video tutorials and the Frequently Asked Questions (FAQ) space.

#### Cooperation Module

1. The system must provide technicians and customers with a shared space to monitor (every minute), graphically, the operating parameters of the equipment of each hospital.
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#### Modeling of the VERA system

Some levels should be considered for the development of the remote system, such as: (1) conceptual and technical architecture; (2) information, covering content (wireframes) and navigational (site map); (3) interaction, which comprises interfaces, mechanisms and navigation aesthetics. Figure 3 illustrates the technical level of the conceptual architecture of the VERA system, built from the abstraction of use-case diagrams (DCU). It is possible to observe the collaborative tools classified according to the 3C model of the VERA system. These collaborative tools are spatially distributed in the interfaces for technicians and clients to perform their tasks from a web browser. In addition, these tools manage and present information about customers, equipment, and users stored in a database [12].

![Conceptual Architecture of the System](image)

**Figure 3:** Conceptual Architecture of the System.

While the second level of information involves content and navigational design, a web wireframe is a visual guide that represents the layout of the web page content, including interface elements, navigation mechanisms, and interaction. The objective of this work is to enable the distribution and interaction of the elements of the 3C model in user interfaces, contributing to a collaborative work environment. The interaction level, which involves the interface and aesthetic design, is based on the master wireframe, which modifies the shared work interface according to the 3C module tool [15]. The interface navigation mechanism is a horizontal navigation menu that was designed according to the informational structure of the system presented in the results. The aesthetic design based on the front-end framework called bootstrap was used, with technologies such as CSS or Cascading Style Sheets, and Javascript being used to define typography, buttons, navigation menu, text boxes, labels, messages, modal windows, datapickers, notifications and wizards. The pages were designed under the concept of responsive design, which allows the interfaces ability to adapt their content according to the size of the browser screen. The build begon with the creation of the database in SQL Server 2012 and the configuration of the APS. NET MVC 5 framework in the IDE called Microsoft Visual Studio 2015. Then the basic web application is generated with the system access and management components of users. From there, the software components are encoded to create the 3C model tools, using HTML5, CSS3, JavaScript 1.8.5, Bootstrap 3, JQuery 1.8. Team Foundation Server is used to integrate components, which offers, in addition to other services, a repository for managing and integrating the source code of the components generated by the developers. Unit tests are run to determine if the individual source code units of software components and their integration are fit for use. Wrong results from unit tests are used to refactor the components. It is worth mentioning that the tasks of coding, integration and refactoring were executed in an iterative and incremental way [16].

#### Results and Discussion

After the implementing the WebE framework iteratively, the VERA system was achieved. The interface, which can be visualized in Figure 4, integrates the collaborative tools in the remote monitoring system of videolaparoscopic medical equipment, providing technical assistance through a collaborative environment. The access tool was implemented in the login interface of the VERA system. This tool allows you to start and log off the system. In addition, it provides a navigation menu depending on the type of user that is logged in. Management tools allow you to manage customer information (hospitals), equipment, and users. Each management tool has been implemented in an interface, which organizes the information into tables. Managing

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**Table 1: System Requirements**

| Requirement | Description |
|-------------|-------------|
| 1.          | The system must provide customers with tools that allow them to contact technical assistance. This communication is asynchronous and text based. |
| 2.          | The system shall provide technicians and clients with a shared space to monitor the state of the alerts from the time they appear on the system until their solution. |
| 3.          | The system shall provide technicians with a chat tool that enables synchronous, text-based communication between the technical assistance team. |
| 4.          | The system shall provide technicians and customers with a shared space to monitor the alerts generated by them. For this purpose, the system offers information search mechanisms by time interval, hospital, equipment, and user. |
| 5.          | The system shall provide technicians and clients with a mechanism for printing or saving the generated reports in PDF. |

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**Table 2: Communication Module**

| Module | Description |
|--------|-------------|
| Coordination Module | Involves the interface and aesthetic design, based on the master wireframe, which modifies the shared work interface according to the 3C module tool [15]. The interface navigation mechanism is a horizontal navigation menu that was designed according to the informational structure of the system presented in the results. The aesthetic design based on the front-end framework called bootstrap was used, with technologies such as CSS or Cascading Style Sheets, and Javascript being used to define typography, buttons, navigation menu, text boxes, labels, messages, modal windows, datapickers, notifications and wizards. The pages were designed under the concept of responsive design, which allows the interfaces ability to adapt their content according to the size of the browser screen. The build began with the creation of the database in SQL Server 2012 and the configuration of the APS. NET MVC 5 framework in the IDE called Microsoft Visual Studio 2015. Then the basic web application is generated with the system access and management components of users. From there, the software components are encoded to create the 3C model tools, using HTML5, CSS3, JavaScript 1.8.5, Bootstrap 3, JQuery 1.8. Team Foundation Server is used to integrate components, which offers, in addition to other services, a repository for managing and integrating the source code of the components generated by the developers. Unit tests are run to determine if the individual source code units of software components and their integration are fit for use. Wrong results from unit tests are used to refactor the components. It is worth mentioning that the tasks of coding, integration and refactoring were executed in an iterative and incremental way [16]. |
| Coordination Module | The interface, which can be visualized in Figure 4, integrates the collaborative tools in the remote monitoring system of videolaparoscopic medical equipment, providing technical assistance through a collaborative environment. The access tool was implemented in the login interface of the VERA system. This tool allows you to start and log off the system. In addition, it provides a navigation menu depending on the type of user that is logged in. Management tools allow you to manage customer information (hospitals), equipment, and users. Each management tool has been implemented in an interface, which organizes the information into tables. Managing |
The system provides query tools that allow you to filter the information presented in the alert interfaces, monitor equipment and display graphics per customer and equipment. The query tools were developed using dropdownlist. The parameter monitoring tool is implemented in the graph visualization screen of the VERA system, shown in Figure 4. This interface provides the shared space to monitor, graphically, the functional parameters of the equipment, divided into two regions: the region on the left is a checkbox list of the functional parameters of the equipment, classified by insufflator, camera, light source and recorder; the region on the right is the graphics area.

Users can choose the functional parameters that are drawn in the graphics area by clicking on each checkbox. The data in the charts are updated (using AJAX) every minute. In this interface you can also see the dropdownlist of the query tool, which serves to filter the generated graphs, according to the client and the selected equipment. Furthermore, in order to monitor equipment there is a modal window of observations containing histories and reports implemented in the graphical visualization interfaces to facilitate the interpretation of information. To achieve this, the system has datapickers that allow you to choose the interval between the initial and final date for the development of reports and history logs of the functional parameters and alerts for selected equipment. Finally, this may be saved in PDF or printed.

The VERA system implements and integrates the collaborative tools for remote monitoring of medical equipment, such as video/laparoscopic equipment, as the purpose of creating a mutual scenario between technical assistance and users during technical diagnosis and maintenance. Collaborative tools are defined and classified according to the 3C model. Coordination tools allow you to organize and query information related to customers, equipment, and users. In addition it offers help materials for the cooperation tools provide the shared space to monitor and display graphics per customer and equipment. The query tools were developed using dropdownlist. The parameter monitoring tool is implemented in the graph visualization screen of the VERA system, shown in Figure 4. This interface provides the shared space to monitor, graphically, the functional parameters of the equipment, divided into two regions: the region on the left is a checkbox list of the functional parameters of the equipment, classified by insufflator, camera, light source and recorder; the region on the right is the graphics area.

Conclusion

After analyzing the development thus far, it was possible to verify that the 3C model has a significant contribution to creating the collaborative environment in the remote monitoring system of video/laparoscopic medical equipment, allowing the technical assistance team to carry out diagnostic and maintenance with speed, enabling an efficient and precise conduct of the procedures of interest through the Brazilian Unified Health System. The authors encourage future research to use the VERA system in the various scenarios that apply to video/laparoscopy, especially situations that demand greater precision and greater equipment performance. In addition, new projections can be cited based on what has been done so far, such as the inclusion of new tools such as calendar insertion, calendars, videoconferencing insertion and application development for mobile devices such as mobile phones and tablets.

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Conflict of Interest

None.

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