Original Article

Prototype of a computer system for managing data and video colonoscopy exams

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ABSTRACT: **Objective**: Develop a prototype using computer resources to optimize the management process of clinical information and video colonoscopy exams. **Materials and Methods**: Through meetings with medical and computer experts, the following requirements were defined: management of information about medical professionals, patients and exams; video and image captured by video colonoscopes during the exam, and the availability of these videos and images on the Web for further analysis. The technologies used were Java, Flex, JBoss, Red5, JBoss SEAM, MySQL and Flamingo. **Results and Discussion**: The prototype contributed to the area of colonocospy by providing resources to maintain the patients' history, tests and images from video colonoscopies. The web-based application allows greater flexibility to physicians and specialists. The resources for remote analysis of data and tests can help doctors and patients in the examination and diagnosis. **Conclusion**: The implemented prototype has contributed to improve colonoscopy-related processes. Future activities include the prototype deployment in the Service of Coloproctology and the utilization of this model to allow real-time monitoring of these exams and knowledge extraction from such structured database using artificial intelligence.

Keywords: colonoscopy; telemedicine; exam management; remote patient monitoring; communication with hospital equipment.

RESUMO: **Objetivo**: Desenvolver um protótipo por meio de recursos computacionais para a otimização de processos de gerenciamento de informações clínicas e de exames de videocolonoscopia. **Materiais e Métodos**: Por meio de reuniões com especialistas médicos e computacionais, definiram-se os seguintes requisitos: gestão de informações sobre profissionais médicos, pacientes e exames complementares; aquisição dos vídeos e captura de imagens a partir do videocolonoscópio durante a realização desse exame, e a disponibilidade por meio da *Web* para análise posterior dessas imagens. As tecnologias aplicadas foram: Java, Flex, JBOSS, Red5, JBOSS SEAM, MySQL e Flamingo. **Resultados e Discussão**: O protótipo contribuiu para a área de colonocospia disponibilizando recursos para manutenção de histórico de pacientes, exames e imagens. O acesso à aplicação, por meio de *browser,* permite maior flexibilidade aos médicos e especialistas. Os recursos para análise remota de dados e exames podem auxiliar médicos e pacientes na realização de exames e diagnósticos. **Conclusão**: O protótipo implementado contribuiu para melhoria de processos relacionados a exames de videocolonoscopia. Trabalhos futuros incluem implantação do protótipo no serviço de coloproctologia, bem como a extensão do modelo para o acompanhamento dos exames em tempo real e extração de conhecimento dessa base de dados estruturada por meio de inteligência artificial.

Palavras-chave: colonoscopia; telemedicina; gerenciamento de exames; acompanhamento remoto de pacientes; comunicação com equipamentos hospitalares.

Study carried out at the Laboratory of Bioinformatics (LABI) at the Universidade Estadual do Oeste do Paraná (UNIOESTE), Foz do Iguaçu (PR) and the Service of Coloproctology (SC) of the Faculdade de Ciências Médicas (FCM) at the Universidade Estadual de Campinas (UNICAMP) – Campinas (SP), Brazil.
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INTRODUCTION

The fast development of the technological area and, in particular, information technology resources, has allowed broad applicability in several areas of knowledge[1-5]. Some developments of the computer area that have contributed to this scenario include: increase in storage capacity, expansion of processing capacity, improvements in computer application safety, development of new data communication techniques, popularization of Internet and web-based systems[4,5].

Based on these developments, the utilization of computer techniques to help medical sciences has provided great contributions, involving the use of varied resources, including: computer graphics, image processing, database, distributed systems, data communication, artificial intelligence[6-14]. This scenario boosts the utilization of computer methods in different medical areas, from corporate solutions to hospitals and clinics to remote patient monitoring.

One important contribution linked with this multidisciplinary characteristics is the remote exchange of medical information, which enables distance diagnosis and treatment[11]. Examples of possible uses could be patient consultation and monitoring, information sharing, discussion of exams and medical inquiries, all made remotely[9,11,14]. These services need effective data communication mechanisms to ensure exchanged information privacy and reliability[15].

Due to the variety of computer applications in health areas, the computer systems have been classified as[13] *Hospital Information Systems* (HIS), *Radiology Information Systems* (RIS) and *Picture Archiving and Communication Systems* (PACS).

The integration PACS, RIS and HIS has been promoted with the creation of standards, such as current *Digital Imaging Communications in Medicine* (DICOM)[16] and *Health Level Seven* (HL7)[13,17]. These multidisciplinary applications, which involve the medical and computer areas, have encouraged the development of various products and studies, in both corporate and academic environments[11]. In this context, the Laboratory of Bioinformatics (LABI) of the Universidade Estadual do Oeste do Paraná (UNIOESTE), in a partnership with the Service of Coloproctology of the Faculdade de Ciências Médicas da Universidade Estadual de Campinas (UNICAMP), has developed several multidisciplinary studies[1,6,8-10,14,18-20].

The model proposed in this study is from the Telemedicine line of investigation conducted by both LABI and UNICAMP. The proposed solution involves the concepts of HIS[13], including data management related to the patients, health professionals, exams and reports.

The prototype includes other functionalities classified as PACS[13], in which a communication protocol is established between a computer system and the video colonoscopy equipment. Based on this interaction, this model provides management of patients' exams, including image and video capture during the examinations. Another important characteristic of this prototype is that it enables authenticated professionals to have a web-based access to patients' exams and data. Then, the development of this study was encouraged for ensuring continuity to previously developed models, this way contributing to exam supervision and offering technological resources that help perform distance diagnoses.

MATERIALS AND METHODS

The proposed experimental model involves concepts and functionalities of HIS[13] and PACS[13]. The development of this study followed methodological characteristics defined by Software Engineering[21], using the *Unified Modeling Language* (UML)[22] modeling.

One of the prerequisites for the development of this study was the study on the problem domain, through literature and meetings with experts, involving the protocol to perform video colonoscopy[23,24]. In addition, the study on items that constitute[23,25] the video colonoscope, such as: communication mechanisms available, differences between components according to the product manufacturer, model, video resolution, image quality, video input and output technology, was extremely important.

Regarding the problem domain, the literature related to protocols, standardizations and classifications of systems used in the medical area – e.g., HIS[13], RIS[13], PACS[13], DICOM[16] and HL7[17] – was also referred to.

After studying the involved domains, i.e. the medical and computer areas, observing real colonoscopy at the Gastrocentro at UNICAMP and having

meetings with experts from the medical and computer areas, the requirements for outlining this model were identified. The main characteristics defined were:

- The system accessibility should be made only by registered professionals, with permission to use the system;
- Maintainability of information about health professionals, patients and exams, using efficient safety and privacy criteria;
- Availability for web-based utilization of the solution;
- Permission to store and manage patient-related information through clinical history records and clinical exams performed;
- Permission to enter and maintain data about health professionals and researchers, who have access to the system to perform and/or analyze the exams;
- Capability to manage data and image captured during colonoscopy;
- Implementation of resources that enable the system communication with the video colonoscope, offering mechanisms for image capture and storage during colonoscopy;
- User-friendly interface to perform and monitor colonoscopy;
- Implementation of functionalities that enable the visibility and analysis of performed exams after they are concluded. For this requirement implementation, the remote utilization of the system should be considered via browser and internet connection.

After the definition of all requirements to be offered by the prototype and considering the particularities of the problem domain, the technological options were analyzed and, with these procedures, the solution model was defined, according to the sequence of architectural, logic/process and data models, presented as follows.

a) Architectural model

Figure 1 shows the architecture of the proposed model, considering the physical arrangement of its components, functionalities offered and technologies used in the solution. The computer model includes the utilization of Hospital Equipment (HE); in this case, equipment specifically designed for colonoscopy (video colonoscope).

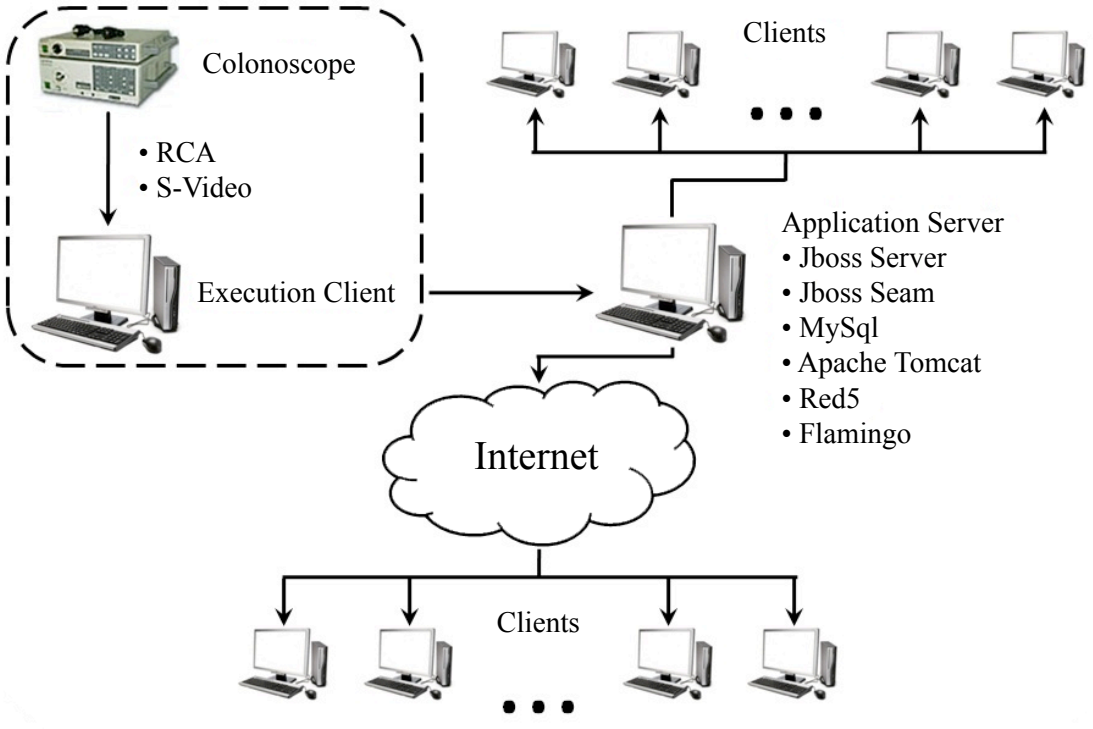

Figure 1. *Architectural model of the solution.*

Colonoscopy is an endoscopic exam that shows the internal part of the whole colon. It uses a flexible tube whose length is 70 to 160 cm. At the end of this tube, there is a camera, which sends images to a display[23]. These images can also be captured and stored in memory cards connected to the video colonoscopy equipment processor[23]. During the exam, images and videos are captured by distinct colonoscopy devices (different manufacturers and models) in *Intensity and Chroma* (Y/C), *Video Graphics Array* (VGA), Super Video formats, in *National Television System(s) Committee* (NTSC) color system. These exams can be monitored directly through the display and the selected images can be printed[23].

This way, video colonoscopes usually have the following components[24,25]: colonoscope (fiberscope), light source, aspiration and biopsy channels, enlargement lenses, air insufflation or irrigation channels, NTSC display with Y/C input and VGA with color and brightness adjustments, trolley or cart for equipment support, video printer compatible with NTSC color system, alphanumeric keys and printer.

As illustrated in Figure 1, the interaction between the video colonoscope and the computer system was defined in this model, named Execution Client. This computer is equipped with a video capture board and is physically located in the exam room. RCA or Super Video connected were selected to establish the communication, interconnecting the video colonoscope output to the capture board input.

The Execution Client has the access to software functionalities classified as HIS[13], such as registration of patients, health professionals and researchers and exams. Besides these functionalities, characteristics classified as PACS[13] are provided, which will be used during the exams, such as capture, monitoring and storage of images from the video colonoscope.

For the proper execution of the defined functionalities, the Execution Client should have the access to the services offered by the Application Server. These services include data management, network communication, functionalities for data entry, management and history analysis of patient and exam data. The technological resources employed to provide these characteristics were defined according to the Logic and Process Model section.

This way, the Application Server enables the services required for an adequate operation of the Execution Client and other Clients. It should be noted that the functionalities not directly related to the exam execution were available to Clients in both local network and internet, by using web technologies (Figure 1).

b) Logic and process model

The outlined computer architecture uses the *Model-view-controller* (MVC)[26] standard and Java programming language[27], JBOSS Application Server 4.2[28], Red5 1.0 streaming server[29], JBoss Seam Development Framework[30] and MySQL 5.1.42 Database Management System[31]. The visual presentation of videos and images and the communication with capture devices used Flex 4.0[32] programming language. The interaction and communication between the classes developed in Java and Flex were established through the access to remote objects, using functions available in Flamingo framework[33].

After the definition of all technological resources to be included in the computer project, the main processes implemented using the prototype were presented.

The main process is related to image communication during the video colonoscopy. For this process, VP-4400[25] Fuginon video colonoscope was used, connected to a Core 2 Duo 2.2 GHz computer, with PixelView PlayTV Xtreme video capture board, through the Super Video format video interface. For the streaming management, a connection with RED5 1.0[29] streaming server was used. The images collected during the exams were stored in the Application Server and the video capture was made by the video colonoscope, but the experiments were not performed during real exams.

For the image capture, H.264 codec was used, with 500 x 500 pixel resolution and 30 fps (frames per second). The images captured during the exams were stored in JPEG[34] format; the visual display of images and the communication with capture devices were made using Flex[32] language.

The registration and inquiry processes related to physicians, patients, exams and images were available to all professionals with system access, either in the institution's network or an external environment, using the internet. These characteristics were implemented in JBoss Seam[30] and the data were stored in a Mysql structured database[31,35].

c) Data model

To support data storage, a data model was elaborated, named Relation Entity Model, and implemented by a Mysql database management system[31,35], composed of the following entities and relations: Professional, for the storage of data related to physicians and professionals that will have access to the system, with encrypted password field, and using MD5[15] algorithm; Patient, to keep the history of patients that will be registered at the hospital or clinic; Equipment, to identify the exam equipment; and Exam, which constitutes in one entity that relates the other tables and stores the data regarding the exams performed, including patient, physician and equipment used, type of exam, medical care and institution where the exam was performed. This table also stores specific information about the exam, such as exam date and links to see the images captured during the exam.

RESULTS

The development of this study enabled the domain study in the medical and computer areas. The interaction with professionals from these areas allowed to list procedures that can contribute to better processes for exams that complement video colonoscopy.

Based on these information, the identification of resources, the evaluation of technological alternatives, the computer project definition and the prototype implementation were performed.

The computer model was defined and implemented integrating technologies based on free software, in such way to fulfill the requirements of layout (user-friendly interface), efficient user safety and privacy and robust data storage and management. Based on this context, the physical, logic and component architecture was implemented, according to the model illustrated in Figure 1.

Regarding the prototype implementation results, they can be categorized into: layout and interface, data management, application safety and availability of mechanisms for local and remote exam supervision and with resources for subsequent analysis.

The system interfaces were standardized, with a management screen and others for data insert, edit, display and other specific actions. These screens were created for the professional entities, patient, institution, equipment, reports and exams. For instance, Figure 2 illustrates the layout generated for the initial screen of the system, Figure 3 illustrates the interface for exam management, Figure 4 shows the screen for

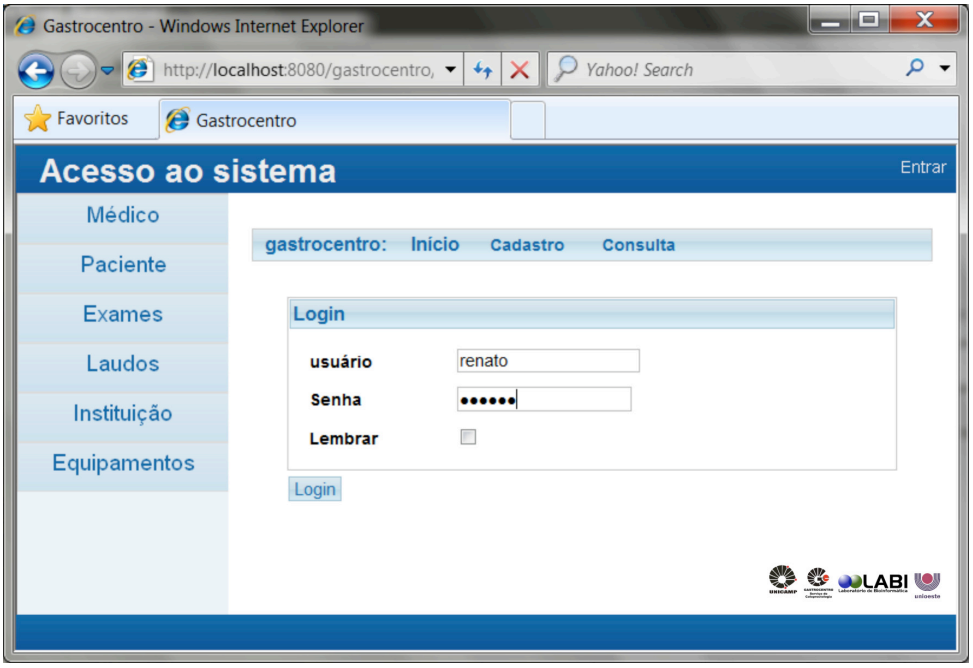

Figure 2. *System authentication screen.*

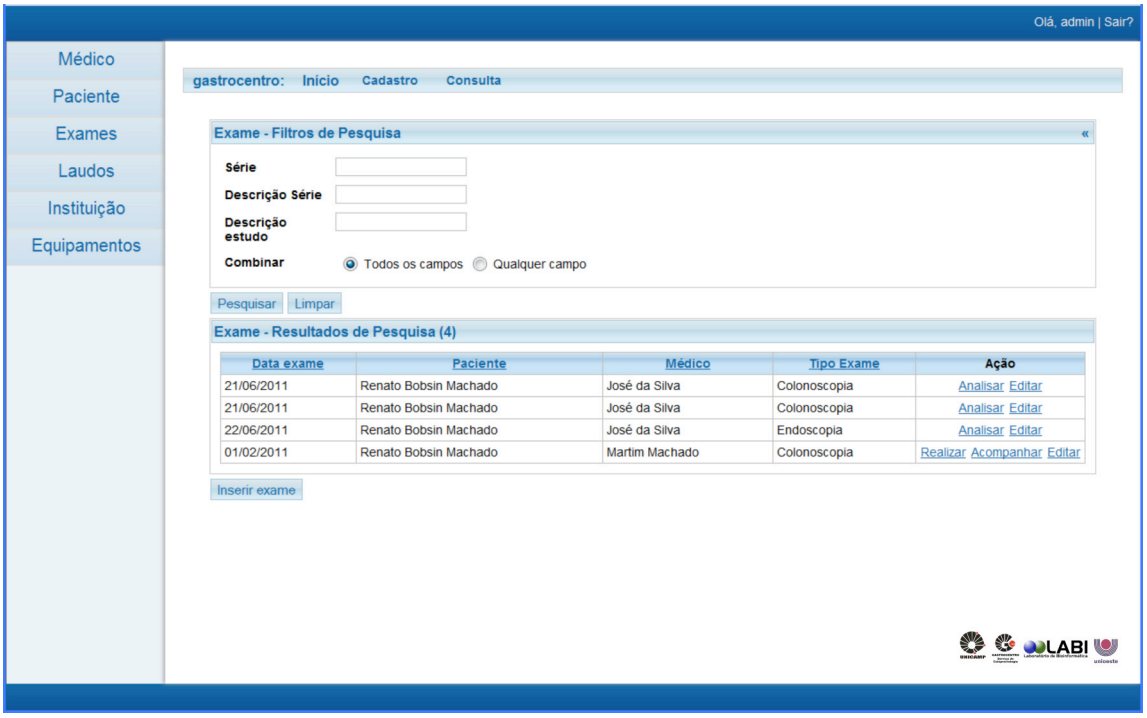

Figure 3. *Interface for exam management.*

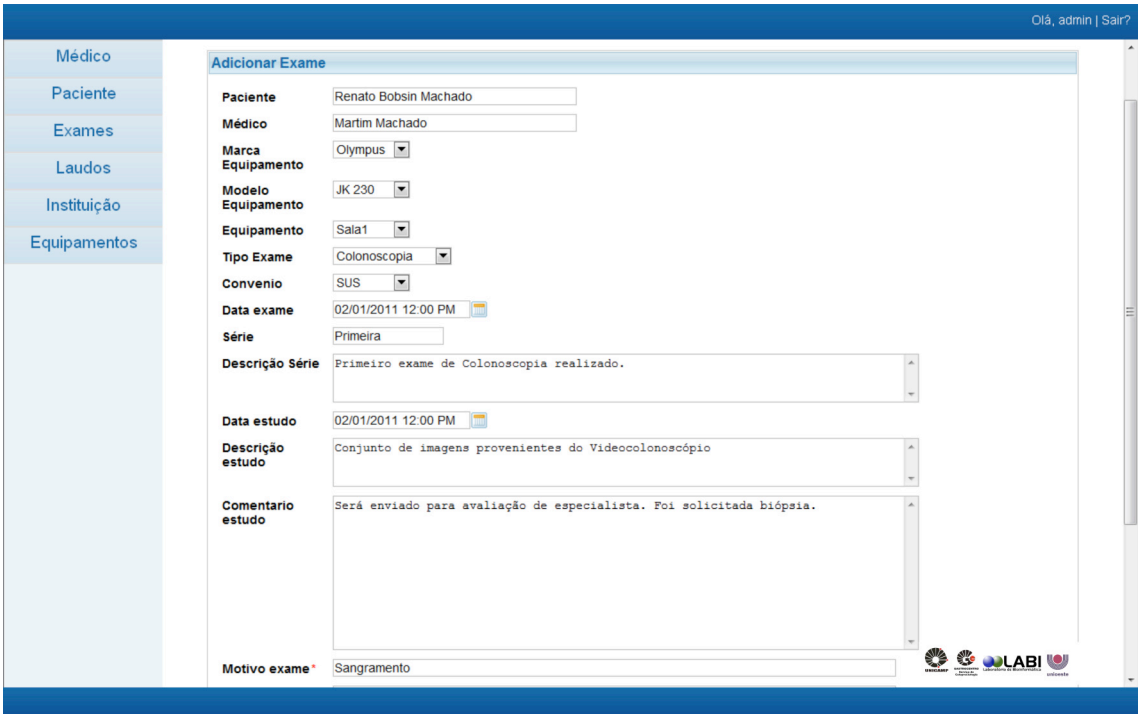

Figure 4. *Screen for new exam entry.*

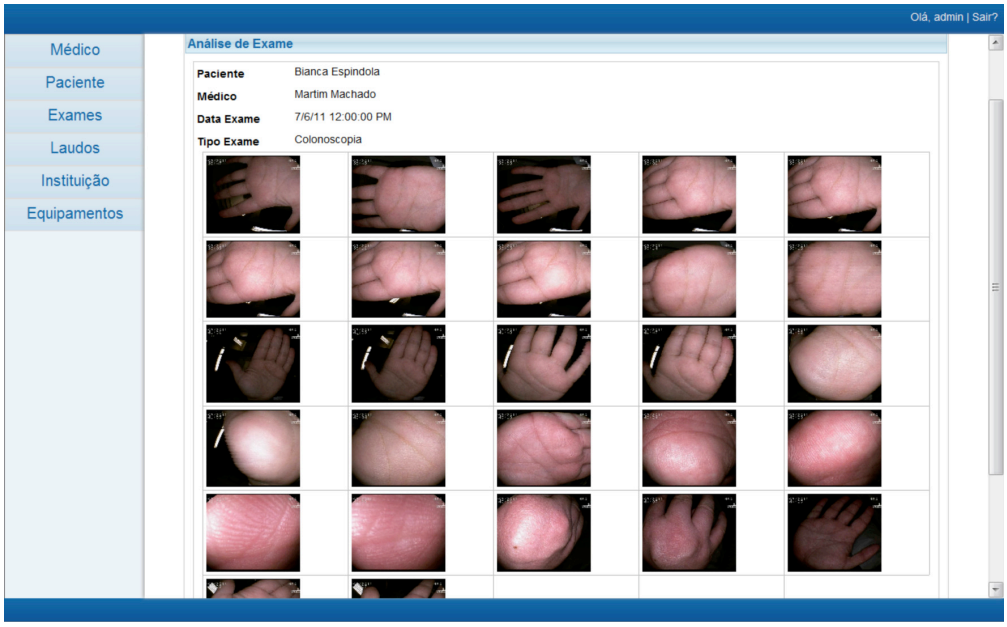

Figure 5. *Interface for colonoscopy exam and image display.*

entering a new exam and Figure 5 illustrates the layout to perform and supervise a video colonoscopy exam.

The figures mentioned above show the main characteristics available on the other screens of the prototype, involving the arrangement of graphic elements, menu bar, navigation mode, indexing and search resources, component to present the results, resources to view and supervise the videos and images from the video colonoscopy, among other characteristics.

Regarding data management, the Relation Entity model was created to ensure integrity and reliability to the storage of data from entities and relations. Besides the specific requirements of this prototype, the base was estimated to allow easy integration with other computer systems for the medical area and the application of knowledge extraction methods.

Besides data layout and model, the data and user safety requirement was implemented by using MD5[15] algorithm, generating a 128-bit hash.

For the prototype development, the integration of JBoss Seam[30] framework with Flex[32] language allowed greater flexibility for the interface and image handling, keeping the MVC[26] model robustness for database management, utilization of efficient encryption methods and prototype development in a web-based environment.

The characteristics implemented in the prototype were validated by experts from the medical and computer areas, with special regards to the functionalities that allow real-time exam supervision and the possibility of future analyses, as illustrated in Figure 5.

DISCUSSION

The prototype development for patient and colonoscopy data management uses the characteristics of HIS[13] and PACS[13].

The web-based access to the application allows greater flexibility to physicians and experts, as the system can be accessed from any hardware or operating system platform, via web browsers, with the internet connection as the only prerequisite[15]. This way, no applications have to be installed to access the prototype and its functionalities, and the architecture provides easier maintainability and transparent incorporation of new functionalities to end users; in this case, health professionals.

These definitions allowed to classify this prototype as an application linked with Telemedicine research. In this context, an important contribution of this study is that it enables physicians and experts to refer to patients' data and exams and discuss cases and interact in patients' diagnosis and treatment, also in

real time. This aspect can also help reduce the impact of geographical distances, considering that, in several situations, the experts cannot be present in all places where they practice, and the lack of experts in smaller cities, far from urban centers.

The resources used to provide system authentication was MD5[15] encryption method, which generates a 128-bit hash. This method is today's one of the most efficient algorithms, with flexibility to determine the key size according to the safety level required[15]. One of the advantages of using this method in the prototype is that both Jboss Seam[30] technology and Mysql[35] database have compatible functions with this method. Then, it was possible to ensure compatibility and the desirable level of encryption efficiency, reduce the development time and enable the encrypted password storage in the database. The system login interface is illustrated in Figure 2.

After the system authentication, the prototype functionalities are ready to be used. The interface was developed using JBoss Seam[30], a web-based platform, which integrates with the data management resources.

Mechanisms were developed in the prototype that integrate the interface with the database to enable data entry, edit, display and removal, keeping functional and referential data integrity. These characteristics were provided for data related to physicians, patients, exams, institutions and devices. The management of such data is performed using the menus on the left side of the interface (Figure 3), which open other screens with specific functions.

One of the prototype advantages is that it combines free software tools, reducing development costs, but keeping an intuitive, user-friendly and easy-to-navigate layout.

The interface provides a search field in the upper part of the screen and the entries stored in the system are displayed in the lower part. These entries are the result of a search parameter, the default is "display all" (Figure 3).

For each entry, links are provided on the right part of the screen for entry view or edit. When opening the edit option, data are viewed with all related fields, which can be altered by the system user. The lower part of the edit screen has the following buttons: Update (save alterations), Remove (remove the current entry) or Cancel (exit the edit mode, keeping the entry unaltered). The lower part of the search results has the Insert button. When clicking this button, an interface is provided to add new entries (Figure 4). These functional characteristics are typical of HIS[13].

The prototype has functionalities that were developed to allow the communication with the video colonoscopy, image capture and display during the exam and subsequent storage. After the conclusion of complementary exam procedure, data and images were available to health professionals via web resources. These functionalities are classified as PACS[13]. To better understand these functional requirements, the protocol proposed for exam management will be discussed.

Figure 3 shows the exam management interface. The insertion of an exam entry usually occurs at the moment the patient comes to the exam room. When clicking the Insert button, the user has the access to an interface to enter exam-related information (Figure 4).

The exam registration in the system requires the following: patient's name, physician in charge of the procedure, equipment to be used, exam date, the patient's medical care, reason for the exam, patient's reference, institution and specialty for which the exam will be performed. To support the integration of this prototype with the PACS model previously developed in this research line[19], optional fields were added of series description, study description and study remarks.

After saving the new exam, other functions are provided, which will allow to go to the exam screen (Figure 5) or return to the exam management screen (Figure 3). For entries of data on exams registered in the system, but that have not been performed yet, actions are provided for exam execution, real-time exam supervision and exam entry edit. For concluded exams, options are provided for analysis, to have access to all exam data and images, and edit, to alter concluded exam data.

When executing the "perform exam" action, the prototype opens a screen (Figure 5) to locally and remotely watch the exam video, allowing to capture images the physician considers important. After he images are captured, at the physician's discretion, the procedure can be concluded.

For the health professional to access exam data and images, he/she should use the "analyze" option in the

exam management interface (Figure 3), on the "Exam Inquiry" screen, as illustrated in Figure 5. The images from the palmar region of hand, illustrated in Figure 5, were used in the validation of exam execution and monitoring functionalities and the analysis characteristic. These images were captured using a video colonoscope from the Service of Coloproctology of UNICAMP.

After the prototype functionalities were outlined, it was confirmed that all requirements defined with the experts had been implemented and that they provide important contributions to video colonoscopy execution; some positive characteristics that could help physicians and experts are:

- Storage of patient and exam data history;
- The possibility of image capture and integration into the system during the colonoscopy execution. The video colonoscopy devices usually store captured images in magnetic media, which should be taken to a computer for visualization;
- The use-to-use, web-based graphic interface;
- The web-based exam and image display, allowing the exams to be remotely analyzed by experts, which contributes to diagnoses of improved effectiveness;
- The system can be used in distant cities without experts in the area, minimizing the patients' efforts of traveling to urban centers and, especially, reducing diagnosis times.

Besides the specific characteristics of the solution presented in this study, this model can be integrated with other studies previously developed in this research line[19].

Regarding the technology employed, it provides the advantage of using all components developed Java[27] and open coding services. These characteristics allow the system operation in any hardware or operating system platform that supports Java virtual machine, as well as reduced development cost, keeping the data management efficiency and the easy navigation in the application screens. The developed prototype was validated in *Windows* and *Linux* operating systems, using *Mozzila Firefox*, *Internet Explorer* and *Chrome* browsers.

CONCLUSION

This study presented a prototype of a computer solution that combines HIS and PACS characteristics.

The development of this prototype contributed to improved processes related to video colonoscopy exam execution, allowing to create a history of patients and exams in a structured database and the remote analysis of patient and exams.

One of the differentiations of this study is in the provision of resources for video colonoscopy exam supervision in real time. Future activities include the prototype deployment in the Service of Coloproctology at UNICAMP, the integration of the database from this prototype with other models defined in partnerships with LABI at UNIOESTE with the Service of Coloproctology at the Faculdade de Ciências Médicas da UNICAMP, and utilization of this model to allow real-time monitoring of these exams and knowledge extraction from such structured database using artificial intelligence.

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