An Open Source Based Radiological Information System to Support a Clinical Cardiology Department

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Abstract

A computer-network infrastructure integrates the different components of the digital radiology laboratory, so realizing a functional island able to provide fast storage and browsing of clinical data, to make them remotely available by means of Intranet tools, and to link them into the central Information system of the CNR Institute of Clinical Physiology, together with the reports. Low cost commercial applications as well as open source programs and advanced operating system (LINUX) guarantee cost-effectiveness, safety, maintenance, and compatibility with the current clinical standards (i.e., DICOM 3.0 standard). Human error has been reduced by means of a careful use of worklists along the patient identification, data acquisition and reporting phases. The approach of the healthcare personnel to the system has been easy, due to the simple operations necessary for the management of clinical and administrative data. Periodic backup allows to safely storing historical data. Remote real-time retrieval of images for diagnostic as well as for research purposes has made easier the approach of the clinicians to digital radiology.

1. Introduction

Computerized medical information systems (IS) have met an increasing diffusion in the last few years, sustained by the consolidation and enhancements of computer technology and standards in data communication and storage. IS are the backbone structure to get efficient and cost effective health care environments. Though digital technology has been active in hospital departments and laboratories, such as those devoted to nuclear, ultrasonic, magnetic, electrophysiological imaging, radiology has been the last discipline to approach the digital world, mainly due to unsatisfying quality of the first digital radiograms, limitation overcome by the most recent technological upgrades. Today, digital radiology is well accepted as an adequate alternative to the traditional film-based systems, for the wider dynamic range, and for having solved problems such as storage, post processing, transmission, retrieval, soft copy, remote display.

The main problem to make radiograms available in a clinical environment is usually solved and guaranteed by expensive, commercial PACS. The "SPERIGEST" project and its subsequent developments, realized at the CNR Clinical Physiology Institute, and sponsored by the Italian Health Ministry, aim to integrate into the Institute IS data, signals, images of the heart, and its physiologically related organs, as produced by both workstations and data sources, independently from the platform. It can be considered a less expensive and a more complete alternative to commercial PACS, as it can be virtually integrated into any hospital information system, allowing also clinical, administrative and overall management of all the activities related to health-care. For its implementation, commercial as well as open source free applications and operating systems are concurring to get this result [1-3].

A carefully engineered management system, based on an efficient local Information System and supported by suitable technology, improves the level of efficiency of the Clinic, with benefits for both the medical, paramedical, administrative components, and for the user (the patient), without radical changes for the clinical routine. This goal can be achieved by characterizing the system with: modularity, efficient protocols, resource harmonization, shortening of exam duration, information, standardization and share (Figure 1).

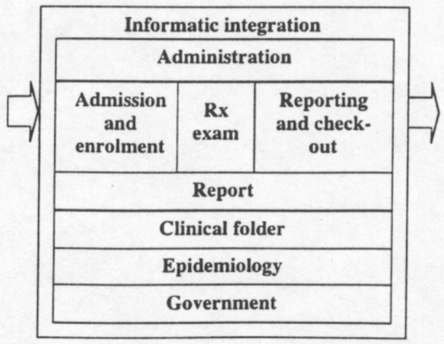

Figure 1. Clinical protocol and integration of the information.

The project should require a limited economic effort, in particular devoted to support the available medical

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instrumentation with suitable technology, to get compatibility and integration.

The aim of the here presented project was to improve the quality and effectiveness of the digital radiology laboratory, to reduce costs of implementation and maintenance, to provide an easier approach of the operators to the information tools and to the digital instrumentation, by employing low cost commercial, as well as free Open Source [4] tools taking into account the needed guidelines about the data safety and security.

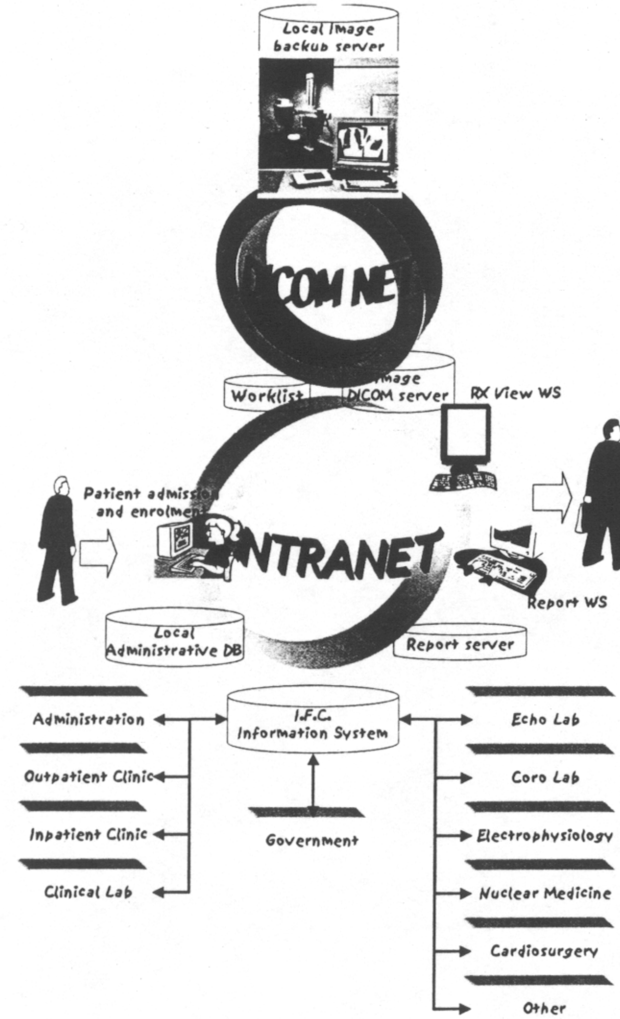

Figure 2. The radiology lab network.

2. The 'functional island'

To get the best synergy between clinical needs and available resources, the radiology laboratory includes a complete set of hardware and software tools for data acquisition, image processing and storage, report implementation and archiving, in order to realize a complete, self-sustaining, integrated 'functional island'.

The digital radiology equipment, actually available at the IFC, is an Imix Thorax 2000 (IMIX, Germany), producing 2000x2000 pixels, 10bit images, locally stored in a format based on ACR-NEMA standard, but also able to store them into remote systems running DICOM 3.0 [5] protocols for both network transmission and radiogram storage.

Particular care has been devoted to the creation of a database of digital radiograms, accessible, in real time, in the standard DICOM format, by any clinical and research user of the Institute, and, under suitable safety and security conditions, externally. Digital radiograms from the DICOM compliant digital radiology acquisition station are transferred to the dedicated DICOM server, through a DICOM network. A multifunctional server has been implemented on a 2.0+ Ghz AMD Athlon XP based equipment, running LINUX RedHAT 8.0 operative system. The server has a double network link, one towards the DICOM local net of the laboratory, and the other, by means of a second network card, looking at the Institute Intranet LAN network: the two environments are therefore distinct, and, at the same time, the stored databases and worklists are available to users of both the networks (Figure 2). The server includes: the DICOM radiographic image database, the administrative and report databases, the worklists.

The DICOM network is the local network of the laboratory, connecting the radiology acquisition system, the film printer and the image DICOM database and worklists. Secondary peer-to-peer links are available between the acquisition processor and the operative console, and towards a local image backup server, set to store radiograms in a format compatible with the IMIX system.

The image data can be accessed by any Windows/MacOS/Linux based PC, set up in the Institute Intranet network: images can be retrieved in DICOM format for browsing and conversion into the desired image format, for subsequent integration into presentation and reporting files (eFilm, Merge Efilm, Canada). The image database allows also the integration of the radiographic data with the cardiac images yielded by the other available clinical imaging modalities of the Institute.

A client-server configuration has been chosen to access the local administrative and report databases, from the workstations devoted to patient admission and enrolment, as well as to reporting. The tools for the management of administrative and clinical data have been developed employing Filemaker Pro v.6 (Filemaker Inc., USA). Physically, the server functionality is split on two separate equipments. As above said, the local administrative and report databases reside on the same storage system of the images; a further personal computer transmits new reports towards the central IS. A suitable middleware, based on JAVA [6] servlets allows to make data compatible with the central IS, based on IBM dB2 [2]. This architecture has been demonstrated to be a winning solution in other functional islands, previously developed in the Institute [3]: in facts, not only the functional island can keep an autonomous activity, avoiding to stop, for instance, in case of network fault, but also the intrusion of external hackers is highly discouraged.

Multifunctional workstations, including the tools for image view and processing, the browsers to access informative data provided by the IS via a secure web site, and the applications to enrol the patients, to create clinical reports, and to access the databases. Encryption has been adopted for the transfers between the clients and the server; secure transactions and firewalls provide further blocks to undesired external accesses and attacks. Internally, the access to the system is controlled by means of passwords, while log files record the main activities of the users (log in, log out, admission, reporting, browsing), in a proxy-server-wise way of work.

The tools for the creation of the rough reports on the client workstations are structured to help the users during the editing operations of the final report. To ensure the legal validity of the final report, a unique original print is produced at the same time the report is stored on both the local server and the IS archive. Non-legal previews can be printed or viewed, during the implementation of the reports, which are kept stored on a suitable temporary database on the main server, until the user requires the definitive storage.

The access to the IS data for patient identification is obtained by means of ODBC protocols and SQL commands, performed by commercial plug-ins as well as custom scripts. However, a new procedure, adopting the XML tools [7], included in the last version of Filemaker Pro, has been developing, in order to bypass the use of commercial plug-ins. XML tools have been also realized to create worklists, compatible with DICOM standards. In particular, during the phase of admission of the patient to the laboratory, the operator introduces the surname, and optionally name and birth date, just once, to get identification and administrative data from the central IS. These data are available to both the reporting system and to the acquisition radiology system, by means of the automatically created worklist, with no other unnecessary human intervention. This allows reducing many possible causes of mistake while transferring the patient data to the different destinations (for instance, a repeated hand typing can yield wrong spelling). A further advantage is to give to the images and to the report the same identification codes to recover them without impairment.

Relationships rule the access to local databases: a unique key is used to store the administrative and report data for new examinations, while multiple relational keys are available for the retrieval and the browsing of the saved reports.

The user-friendly, intuitive interface reflects the traditional structure of the paper records: a folder with tab-pages. Each tab-page represents one piece of administrative and/or diagnostic information, including: individual laboratory test results, images, and diagnostic and therapeutic conclusions. Menus, intelligent auto-editing, button-driven input of most used expressions are among the facilities for a quicker report edition. The application is started by a password-based login procedure, which allows the identification of the user and the authorization to access patient information according to user-specific rights. For new examinations, three sources are available for the acquisition of the identification data of the patient: the direct input from the central database, where admitted patients are regularly recorded; the local server, where the data of formerly examined patients are saved, in the case of fault of the net external to the functional island; the manual input by the operators. Of course, the data can be integrated or corrected by the operators, before storing them into the local server. The creation of an administrative new entry opens the file relative to that examination, whose record is definitively closed only when the test is finished, and the report is printed and signed by the physician. This means that the protocol can be suspended as well as divided into steps, and the report updated time by time. The final report can include the images as a complement of the alphanumeric data and comments.

Network transactions between the databases are via Ethernet networks, using the TCP/IP transfer protocol.

Secure data transmission from and to the central IS is made safe by the concomitant employment of firewalls, encrypted data transmission and password-enabled access. Of course, IS-resident information is accessible via secure links. The paperless medical record resident on the local server can be viewed and printed by means of a custom application, allowing both patient care support and playback consultation for clinical research. Images are integrated into the diagnostic reports, to document findings and results, in JPEG format; the original sets of radiograms are available only on the DICOM archives, through safe and secure access.

Statistical reports can be created and electronically sent to the managements of the laboratory and of the Institute, to check the activity. Browsing and search of the reports can be performed by means of many search keys, to accomplish clinical and research studies.

3. Open source technology

The use of suitable Open Source technology [4] yields the development of really low-cost efficient applications, a simplified but complete management of the laboratory, reducing costs and production times. In contrast to commercial solutions, Open Source software allows to access source codes, to verify and eventually to modify them, in order to fulfill the current safety standards for the treatment of personal and sensitive data, at really low costs. The effectiveness of this approach is related to the virtually high number of cross-controls made by the scientific community, including both corporate and research institutes, providing a fast spread of new solutions. Moreover, the virtually immediate correction of software bugs can improve the overall system features.

3.1. The DICOM server

The realization of the DICOM server is based on "imagectn archive" from the open source package DCMTK "DICOM toolkit" from Kuratorium OFFIS [8], slightly modified to accept studies without any limitation, but the server capacity. The storage has been realized in the Linux environment, with technology Raid 1 (mirroring), in order to avoid loss of data in case of fault. The "advanced journaled ext3 filesystem" preserves the radiological data yielded by the diagnostic equipment. This kind of file system avoids the data loss consequent to unexpected reboots, power failure and system lock-ups: in facts, these events can result in significant corruption of recently modified data, when using standard file systems. As a further advantage, the system manager can get rid of the wait times related to the check of the file system, due to the presence of a log file, that traces all the accesses to the disk from the operating system. The system is protected by an integrated firewall subsystem based on "Iptables", a packet selection system allowing a total protection in absence of a firewall appointed to the protection of the functional island. So the system appears strengthened to make it operative also in critical situations.

3.2. Basic Worklist implementation

The use of the DICOM modality worklist server, fed up by the patient identification application, represents the link between the two worlds: after having once introduced the patient name, at the time of the laboratory enrolment, all needed demographic data, from the central hospital administration or the alternative local demographic database, are immediately available at the radiology laboratory, as well as at the reporting workstations. A unique access to patient identification data for every workstation of the environment, including the acquisition equipment, reduces the possibility to wrongly input them into the different facilities and to incorrectly pair images to patients. The worklist server plays this role of link between the identification and reporting applications and the radiological equipment. It has been implemented by means of the DCMTK worklist server, which is fed through a JAVA servlet mechanism [6]. This approach could be employed for the creation of a link among the DICOM world and virtually any proprietary IS. Actually, the worklist results after exploiting the capabilities of the most recent version of Filemaker to query a servlet server and to receive an XML formatted response from it. This servlet-based mechanism of information exchange allows to perform remote procedures calls and to obtain correct records directly created on the worklist server, on demand. Provided that the hosting server has JAVA capabilities, this method could provide remote database interrogations using the JAVA/JBDC technology [6, 9], without using third party drivers or commercial plug-ins.

4. Conclusions

A network-based local information system has been set up, by linking the digital radiology acquisition system, the computerized clinical report workstations, the administrative office, and the core of the system, a DICOM server hosting demographic, clinical and pictorial data, into a stand-alone functional island. Among the immediate fall-outs, the clinical operators have appreciated the real-time access to the radiological data in virtually every remote location of the Institute, though keeping any necessary condition of safety and privacy. The duration of the examination, from the patient enrolment up to the report attainment, is strictly related to the time needed for the image production and medical-diagnostic approach. Advantages have been acknowledged by both clinicians and researchers.

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