AN IMAGE PROCESSING AND MANAGEMENT SYSTEM FOR RADIOLOGY

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Abstract

The morphology of Greece has a significant effect on the structure and operational characteristics of the Greek health care system. The remote location of many rural health care centers and the concentration of major hospitals in the few big cities have an effect on both the quality and availability of health care that is provided. We are developing a strategic plan that would allow hospitals and health care centers across Greece to exchange medical data in digital form and have access to telemedicine and teleconsulting facilities. Two pilot networks are currently being implemented. The first network is designed to allow for telemedicine and teleconsulting services in the island of Evia. The second pilot network will be an IMAC and will be implemented in the Onassio Hospital in Athens. Preliminary results are very promising for the final implementation of this pilot project.

I. INTRODUCTION

The main goal of modern health care systems is the improvement of health of the populations they serve. At present, there is a trend for decentralization of health care institutions and for a move from institutional health care to primary and home care. In many countries, Greece being one of them, health care services are highly centralized. Despite the establishment of well-equipped rural health care centers during the past decade, there are a number of problems, such as personnel shortages, that still limit the quality of healthcare provided outside the major urban centers. While there is an oversupply of university educated medical personnel, there is a corresponding shortage of technicians and nursing staff. Problems are aggravated by the reluctance of many medical and paramedical personnel to work in rural health centers.

The increase in the volume of medical data generated by the use of modern imaging modalities (X-ray, CT, MRI, PET, DSA, Ultrasound, etc.) makes the management of medical data increasingly difficult, both for small and large medical institutions. Furthermore, there are delays created in accessing the volume of examination reports, that lead to increases in hospital patient stay time and an overall increase in the cost of health care. Clearly, an integrated medical data management system which can compensate for personnel shortages and allow for better quality health care to be provided at local level would be a major improvement [1].

In recent years, a number of telemedicine and medical data management systems have been developed in Greece. Most are small scale installations for private practices and clinics. In the public sector, the University of Athens and the Sismanoglio Hospital of Athens have developed a teleradiology network which links selected rural health care centers with the Athens hospital, focusing on transmission of scanned x-ray films via phone line modems. Due to a number of reasons, the system has seen only limited use up to today. The Technological Institute of Crete (ITE) has developed Image Management and Communication System (IMAC) software based on UNIX and X-Windows technology. There have also been a number of efforts for telemedicine ECG networks, with a number of systems, both analog and digital, in daily use. Summarizing, despite a number of past efforts, there are no teleradiology links which operate routinely and on daily basis, and no IMAC integrated systems have been installed in any hospital in Greece.

Considering all the above, we have decided to develop a countrywide strategic plan whose implementation will benefit both small and large health care providers, as well as patients. The architecture of the system was based on international standards, and should allow the accommodation of older technology imaging equipment without digital data outputs. A distributed design approach, as described in [2] was followed. This approach allows for modular implementation and

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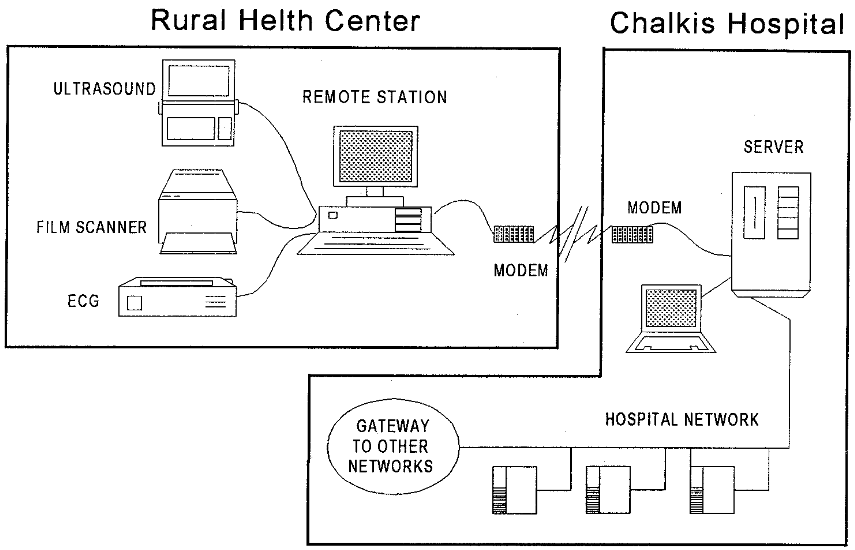

Fig. 1. Schematic representation of the Evia network connecting several rural health centers with the Chalkis General Hospital.

incremental growth which is important, since cost-benefit analysis methods for an IMAC system may be inconclusive [2]. Modularization provides for an answer to this; even though overall costs may be higher, this fact may be deemed preferable to a larger initial financial outlay.

The physical network, which will form the backbone of the system, will be based on open architectures and technologies. Since the system will be DICOM 3.0 compliant, Ethernet topologies and TCP/IP communication protocols will be used. An important provision in the design will be the possibility of having access to remote medical data sources for telemedicine and teleconsulting purposes. These sources can be located in remote areas of the hospital, other city hospitals, rural health care centers and even international medical resource sites, if allowed by the communications infrastructure. The provision of such services will help in the improvement of the quality of the provided health-care in rural areas mainly, and would reduce the problem of heavy patient load in the major hospitals, since many simple cases could be treated locally and not referred to a larger hospital as is many times the case today.

As far as the management software is concerned, there will be a distributed medical database design, and the data could be replicated to one or more servers. Data would be stored locally for a relatively short period due to size limitations for magnetic media, but the system will have the capacity to increase local storage if this is deemed necessary by scaling up the hardware, software or both.

Rural health care centers or other medical data generating facilities will be capable of accommodating film scanners, Ultrasound, and ECG systems, with local but limited database storage capability and will also be able to forward the medical data through the telephone system, the ISDN network, or other technologies. The receiving station configuration could be as simple as a PC with appropriate hardware and software, or it could be scaled up with more powerful databases, extra data storage space, separate viewing stations, gateway to the hospital HIS (Hospital Information System), the Internet, etc.

II. METHODS - DESCRIPTION OF THE SYSTEM

As previously described the system consists of two main parts. The first pilot network connects several rural health centers in the island of Evia with the main hospital in the capital city of the island, Chalkis. A schematic representation of this network is shown in Fig. 1.

This network will provide telemedicine and teleconsulting services to the rural centers. The system is designed to support, on the remote side, input from a film scanner, video output from Ultrasound or other systems, and ECG signals. Data transmission will be either over leased phone lines, or the national packet-switched data network, also known as HellasPac.

The system that will be installed in the rural centers consists of a laser film scanner manufactured by Lumisys, a PC with appropriate hardware for image capture and software for data management and digital data forwarding to receive stations. The communication interfaces will depend on the kind of link that is available. The health centers are equipped mostly with conventional x-ray machines, ECG systems and some have Ultrasound systems. The complete teleradiology network was designed as one standalone unit, with emphasis on simple operation procedures which could be followed by operators with little training on the system. The user interface [3] minimizes the chances of operator errors. It was important not to impose any major changes in the normal operating routine for developing x-ray films for the operators, or increase their workload. Factors like these lead to the failure of earlier telemedicine projects and therefore were given a lot of attention during the design phase.

Along that direction, a Lumisys film scanner was selected due to its simple operation and its high scanning quality. The Lumisys scanner has a single control button which aborts the scanning procedure. The operator only needs to drop the film into a slot, without worrying about any special positioning actions, and all other operations are done automatically. The operator can then press a key on a PC keyboard to send the scanned image to the receiving station, without worrying about setting up the telecommunication link, whose operation is pre-programmed. If needed, further actions can be taken, such as attaching patient demographics to the image before forwarding it, or storing the image in a patient "folder" type of database structure. Memory and disk space can be upgraded to allow for increased data storage.

The receiving station consists, at its minimum configuration, of a PC with a telecommunications interface (modem, etc) and appropriate software. The PC stays continuously on-line and when data is received. the information is automatically stored into a "folder", according to the demographics information provided. The operator can then access the file and review the image on a computer monitor, while the system can continue to receive and store medical data in the background. The receiving system can be expanded to a networked system, allowing for remote viewing and processing of imaging data.

A more advanced database, similar to that of the second pilot project described in the following section can be added in order to handle increased image data information, with transparent handling of on-line and off-line storage media. The data can also be forwarded further to other telemedicine stations, if required.

Cost considerations, mainly on the side of the rural health centers, placed some restrictions on the extent of conformance to open architectures and standards. However, it is expected that the system would eventually be fully DICOM 3.0 compliant. Integrated teleconsulting facilities can also be added as an option, whether voice only, video only, or video and voice. It is also planned to have video, voice and data exchange, with whiteboarding capabilities, when the link operates under TCP/IP.

The ECG subsystem operates in a similar way, but since the data are already in digital format when they appear at the PC's input ports, and data bandwidth requirements are far lower than those for images, the operation is less complicated.

The second part of this pilot project is the development and implementation of an IMAC system which will aid the administration and management of imaging and other medical data in the Onassio, a major hospital in Athens. The hospital has a number of imaging systems, most of them provided by Siemens. Specifically, imaging systems that will be connected to the IMAC network are two color doppler Ultrasound units, a gamma camera, two angiography units, and a number of ECG systems (Fig. 2).. In addition to these, video-conferencing and external networking capabilities will be integrated into the system, along with real time video storage and retrieve facilities for the Ultrasound and if possible, the Angiography units. The hospital has a HIS (Hospital Information System) based on Oracle database technology and running over a 10 Mbps Ethernet network with coaxial cabling on IBM RISC 6000 servers. There is no existing connectivity between the medical imaging units, or between any unit and the HIS.

The hospital staff expressed a strong interest in integrating the IMAC and all its components with the HIS network and provision for connectivity to outside networks and the Internet. They also requested for a high quality full screen videoconferencing component which would be used to carry video from an operating theater for training purposes. The staff also felt that the cost for the IMAC system would be justified by the flexible and timely access to exam report data, which would have a resulting decrease in patient hospital stay time. However, they felt strongly that the system installation should cause minimal interference to their daily routine, and this applied mostly to the actual cabling installation for the network.

The IMAC system is based on a distributed

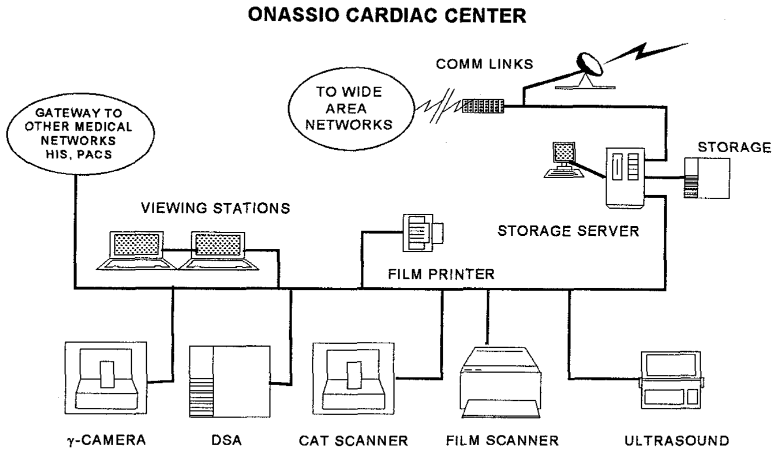

Fig. 2. Schematic representation of the Onassio Cardiac Center fast hospital network linking several imaging modalities to a central processing unit.

systems model, as described in [2]. A distributed approach allows for a modular design, so that additional modules and capability can be added to the system as needed. In addition, some of the imaging systems in Onassio Hospital have add-on post-processing modules connected to them, with the result of having binary medical data files stored on magnetic media in several hospital locations. Some of these files are in formats which although are proprietary, sufficient information exists for their conversion to DICOM 3.0 standard. Other data files cannot be interpreted outside their propriety system, and so other sources, such as video outputs will be utilized. The gamma camera has an add-on module which is based on a DEC (Digital Equipment Corp.) Workstation. This module produces files that can be converted to the DICOM 3.0 format. An initial approach is to use a client-server design, making the DEC workstation an NFS server with appropriate software, and thus open and read the data files from a remote client over a TCP/IP - sockets transport mechanism. A similar approach can be used with the ECG units, which are connected via a proprietary RS-232 network to a central station of Siemens design. According to Siemens, it is feasible to translate the ECG data file format to any other format desired.

The imaging systems described so far produce still frames or sequences of still frames, i.e. not real-real time information. That means that the processing and network transfer of such data can be organized in a way that the developers decide is appropriate. The Ultrasound and Angiography units however produce real-time video data which pose a unique challenge to any networked implementation. The digital video data (which are produced after the digitization of the analog video data stream at a very high sampling rate) are "streaming data", that is if momentarily processing, such as writing to disk, stops for whatever reason, data is lost.

Because of the high bandwidths taken by such data, the collisions which are unavoidable in network topologies such as Ethernet can lead to further loss of information. Since the network bandwidth taken by a single uncompressed video stream is over 60 Mbytes/sec or 480 Mbps [4], it is obvious that some kind of compression is required. However, for compression rates over 3:1 or 4:1 there is detectable information loss which is critical for medical imaging applications. The cost of implementing video servers suitable for storing real-time broadcast-quality video at low compression rates is very high, and magnetic media storage space requirements are substantial. After consultation with the Ultrasound users, it was decided to proceed with the design of a video server which would work at MPEG compression rates and decide whether the resulting image quality would be acceptable to the users themselves. A PC was fitted with an MPEG encoder card with Super VHS quality video inputs, and it was linked via the network to other PC's with professional quality MPEG decoder cards with Super VHS quality video output. The issue was to determine how close the picture from the decoder output resembled the picture on the Ultrasound monitor. The Angiography units provided a greater challenge, since the video output from these machines approached a resolution of 1200 lines, making it very difficult for the video input sections of the currently available MPEG encoder cards to lock on to the signals. A number of tests are planned, and a conversion of the video output to a more manageable signal will be attempted.

In addition to storing real time video, there is a requirement for saving Ultrasound, gamma camera and Angiography outputs as still frames or sequences of still frames in DICOM 3.0 format. Here, a "bridge box" takes the video output from the various units as input and produce still frames with full DICOM 3.0 automation (i.e. the exam results can be stored directly at the chosen DICOM 3.0 storage station, or viewed at the chosen DICOM 3.0 viewing station). Although viewing storage stations are designed primarily as DICOM 3.0 devices, they will also allow handling of non-DICOM data.

The networking backbone is based on 100 Mbps Fast Ethernet technology, utilizing UTP5 type cabling in a star configuration. The Fast Ethernet topology was chosen because wiring costs are low, it can be easily interfaced to the existing hospital Ethernet network, and if the available bandwidth is exhausted, network segmentation methods using switching hubs can be implemented relatively inexpensively. A point-to-point ATM (Asynchronous Transfer Mode) network segment is also used in order to implement a high quality video-conferencing facility, intended mainly for the transmission of pictures from an operating theater to trainee doctors. The main reason for using ATM was the fact that the NTUA possesses the know-how for successful ATM implementations, and the technology will be the only realistic option for cross-border videoconferencing when the national ATM backbone and the European ATM backbone become a reality. Due to the high costs of ATM implementation only two nodes will be connected to the ATM segment, but if required, an ATM switch and additional nodes can be added. The ATM segment interfaces to the Ethernet segments through an ATM-to-Ethernet software router has beem developed at NTUA.

The database component will follow the distributed approach, as described in [2]. The database will be broken up into fragments of data, located at several network sites. In addition to the distributed database model, a second database will be utilized, mainly for handling the mass storage media and operations such as pre-fetching imaging data. It is planned to use IBM DB/2 technology, mainly because it allows to incorporate custom designed image data extenders into the database. Whereas the distributed database will use a relational model, the second database will use an object-oriented model. This will be useful for performing content-based queries on some image data, with color doppler Ultrasound planned as the first attempt. DB/2 technology allows for the queried images to be on a fixed disk, network drive or even CD-ROM or other Optical disk drive while a QBIC (Query By Image Content) can be performed, based on the colors, shapes or textures of an image. The second database will add some complexity and cost to the project, but it was selected as the most efficient way to deal with the problems of accessing long-term mass storage devices in a scaleable manner, implement strategies such as pre-fetching of images in a folder, and provide for intelligent classification of data and feature expansion. Data security was also an important concern, and this can be addressed by the DB/2 product in a way satisfactory for the users.

III. RESULTS

A skeleton teleradiology system for the first pilot project has been already implemented and is being tested. It incorporates a Lumisys film scanner, which interfaces to a PC, appropriate hardware (specialized screen card and 1024 x 1024, 256 gray scale 20 inch monitor) and software for the PC, and a leased line asynchronous modem operating at V34 mode. A PC with Microsoft Windows -based software and a similar modem are installed in the hospital receiving site. Initial tests indicate successful transmission of x-ray radiographs with satisfactory results. Operators have been able to operate the system with minimal training and deflection from their normal operating routines. Similar results have been obtained with transmission of ECG signals. A dedicated ECG monitor in the form of a PC add-in card with supporting software has been developed and tested for this application [5,6]. Further additions, including a more robust database filing system will be incorporated in the network before the final implementation phase. For the second part of the pilot project, considerable work has been done with encoding, decoding, transmission and storage of real-time video using MPEG compression. Despite the high levels of compression, Ultrasound operators have indicated that at bit rates of as low as 4 Mbps the decoded images are satisfactory, at least for consultation purposes, when using color doppler ultrasound. The video server design can accommodate other compression technologies such as loseless or lossy Motion JPEG. Additional testing using various compression ratios is in progress. The same technology is also being used for implementing high-fidelity videoconferencing over the network, with a minimum of 2 Mbps bandwidth needed for this purpose. This system has been tested by performing a video-conferencing connection with a site in Brussels, Belgium at a rate of 2 Mbps. NTUA has also developed an ATM card based on PC ISA bus standards in order to provide for a high speed link for video data transmission. Existing high data rate links are expensive and are not considered a practical proposition for routine international videoconferencing. It is expected that ATM technology will provide a suitable solution to this problem soon. The ATM segment of the network is interfaced to the Ethernet segments through a software based ATM-to-Ethernet router, developed at NTUA.

IV. CONCLUSIONS-DISCUSSION

We are developing a strategic plan for a country-wide infrastructure for medical image data exchange. The initial implementation has two pilot stages, one connecting rural health centers in the island of Evia, Greece with the major hospital on the same island, and the second linking a variety of imaging modalities in a major Athens hospital in a standards-based IMAC network. Preliminary results including ECG telemetry systems, and real-time video transmission are very promising for the successful completion of the project.

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