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Review Paper

Medical Images in Integrated Health Care Workstations

Abstract: The difference between an invention and a discovery is discussed, before turning to the sources of medical images. Next, the ongoing integration of image modalities in clinical routine is reviewed, as well as improvements in diagnosis and therapy planning with the help of better images in inter-connected distributed systems. Current shortcomings of image processing, and the attempts to overcome these shortcomings are presented. Examples of image processing are given, together with a vision on future systems and procedures.

Keywords: Imaging, Image Processing, Workstations, Integration

1. Historical Introduction

On November 8th 1895 Conrad Wilhelm Röntgen, in his laboratory in Würzburg, observed the glowing of a fluorescence paper at a position where there should be no fluorescence.

The *venia legendi* of Röntgen was anything but straight forward. Born in Lennep, a town in the Prussian Rhine Province, on March 27th 1845, he was raised in the Dutch town of Apeldoorn. He failed to get an entrance ticket for academic education, the "Abitur", due to a "zeer slecht" ("very bad") grade in physics and comparable bad marks in ancient languages. Only the famous Swiss Polytechnikum in Zürich accepted him as a student. Twenty years later, Einstein profited from the same Swiss generosity. After getting a diploma in engineering, Röntgen wrote a theoretical thesis on the properties of gases. He then followed his physics professor, August Kundt, from Zürich to Würzburg.

Again, his academic career was stalled, due to the missing "Abitur". Luckily, the newly founded university of Straßburg was willing to accept him as an associate professor (1876); he soon left to become a full professor in Gießen (1879). He was known as a proficient and careful experimental scientist but "he contributed no significant new facts" [1]. Nevertheless, he finally made it back to Würzburg as a full professor, because the two colleagues placed higher on the list declined the offer (1888).

The famous discovery of November 1895 was a result of his experimental expertise. He used a glass tube for the observation of cathode rays, discovered by the physicist Philipp Lenard just two years before. Röntgen did not even build the tube himself but ordered it from Lenard who sent him one of his own devices. While carrying out his experiments in the dark, in an attempt to understand the glowing of low-pressure gases in an electric field and the exit of cathode rays (today we call them electrons) at one end of the glass tube, he observed the fluorescence in a position far off from the known cathode rays.

He concluded that this fluorescence was induced by unknown rays that could penetrate a number of materials which seemed translucent to the rays. Holding anything at hand in the lab, like cardboard or a book, into the unknown rays emitted by Lenard's tube, he saw "the bones of his hand in the less dark shadow of the hand itself".

He wrote a 10-page publication in December 1885, printed it himself, and sent 100 copies to colleagues all over Europe, on January 1st, 1886. The paper was not peer-reviewed but resulted in a sensation, with 1000 copies published on the new X-rays the following year.

Both physicists and physicians worked with the new method; medical diagnosis was catapulted into a new era. Röntgen contributed only two more scientific papers on X-rays in the next 10 years. The animosity between Lenard, the inventor of the tube, who tried to claim some of the fame for himself, and Röntgen was never solved. Röntgen was awarded the first Nobel prize in Physics in 1901. Albrecht Fölsing, who wrote a book on the developments induced by Röntgen's work, mentioned that "sometimes there can be a big discrepancy between the importance of a discovery and its discoverer".

2. General Aspects of Imaging in Medicine

Computer technology made its way into health care during the last 30 years. It started with cardpunch technology in the Sixties, first mainly in administrative applications. Signal processing techniques were used to gather large amounts of new data in an attempt to describe health by quantitative descriptions, e.g., in clinical-chemical laboratories. All data sampling, especially in a clinical environment, resulted in large-scale data collections on paper, but the data were in non-compatible, non-standardized forms. The amount of data was growing fast.

In the course of their clinical history patients undergo a number of examinations: From general practitioner to specialists; through different diagnostic facilities; into the clinic and back to a practitioner or a rehabilitation facility. The data were never generally available. Traditionally, the majority of examinations was performed more than once, due to financial interests and forensic aspects.

Improving image-based diagnoses, classic X-rays, computer tomography (CT), ultrasound devices (US), magnetic resonance tomography (MRI), etc. improved the insight into disease and body with an ever-increasing quality. The newer technologies, mainly CT and MRI, were feasible only through the availability of the equally dramatically developing computing technology. The diagnostic machines were run in the radiology departments because of the specialized knowledge needed to handle them. At the beginning, the costs of these new techniques were very high, which led to the machines being made centrally available, for common use by the different medical specialists.

The results of patient examinations were documented on paper and film (sometimes travelling with the patient, sometimes sent directly to the GP or other specialists). The computers used for CT and MRI were completely unknown to the physicians. The data ware not available in digital form, though they were produced digitally. The resulting images were printed on silver films as in the days of Röntgen, and stored in archives along with the other paper-based files. Improvements in storing, and transmitting this information were not made. Only in the last 10 years, some isolated attempts were made in this direction; though PACS systems were still limping behind.

3. Technical and Organizational Aspects of Integrated Health Care Workstations

3.1. What the Clinicians Need

Experience shows that those who work with clinical workstations do not aim for complicated and highly sophisticated image analysis functions. What they need is the "full integration of images at all". First of all, they need the images to be displayed in their clinical workstations. Highly sophisticated image analysis functions will be required only after this has been achieved.

A technical prerequisite for images in the Health Care Professional Workstation (HCPW) [2] is the realization of the electronic patient record (EPR), also called a computer-based patient record (CPR), e.g., implemented in the Hospital Information System (HIS) [3-6].

3.2. Origin of Images: the PACS

Most of the medical images are generated in the radiology department of the hospital. Other sources are, for example, cardiology, gastroenterology, pathology, dermatology, hematology, surgery, pediatrics, and dental clinics. Modern imaging systems in the radiology department directly produce digital image data such as CT or MRI. These systems can be connected to a local-area network based on Ethernet, using DECnet, or TCP/IP protocols, or may be integrated with a picture archiving and communication system (PACS) [7-9]. The PACS concept emerged around 1980. The target was to replace film as much as possible. However, the realization of PACS has not advanced as rapidly as expected due to technical limitations, such as the amount of data, image quality, or integration with RIS/HIS [10]. Today, only some of the full-scale PACS for radiological images are really operational [11-17]. Wide acceptance is hampered by the costs of such systems and their significant organizational impact [10].

In reality, the technical solutions were insufficient, not practically usable and much too expensive. Technology, clinical application, and economy are still the major benchmarks to justify the implementation of the new-generation PACS. Contrary to the early days of implementation of PACS, progress in commercially available computer systems in concert with intelligent image-management software allows a stepwise or overall application in radiology and beyond, with the potential of amortization within 3 to 5 years [18]. Meanwhile, many "MiniPACS" solutions have been installed which do not try to solve all PACS problems at once, but concentrate on (low resolution) digital images (e.g., CT, MRI) [19-21].

The digital modalities, i.e., the PACS, have to be integrated into a HIS to be able to integrate the images into the clinical workstation. The many problems which may occur in this integration process are described in the literature [22-25]. The problems have been recognized and solutions are emerging [10,26]. For example, the generic HIS/RIS-PACS interface HIPIN was designed, implemented and evaluated within the EuroPACS project [27,28]. But a result of HIPIN was that the communication standards have to be extended to match the advanced interoperability requirements for (parts of) the hospital information systems of today [27].

The problem in integration is not primarily a lack of messaging standards in the HIS context. In fact, many standards have been established and are in use, such as ACR/NEMA, DICOM, ASTM, HL7, IEEE-MEDIX, EUCLIDES, and EDIFACT [29-31]. The problem is that all of these standards are different and that they have to be integrated, interfaced, and translated [31,32].

DICOM [33], HL7 [34],and EDIFACT [35] are of special interest for the integration of images with a HIS. HL7 is an established "industry standard" of HIS in the USA, whereas EDIFACT is the standard of the European Committee for Standardization CEN (TC 251). DICOM is the equivalent standard in radiology to communicate and archive images. It has been an official CEN standard since February 1996, which means that it will be the ISO standard in the future. They have not been designed to be compatible with each other. Local solutions have been realized to interface both protocols, e.g., [36,37]. CEN is currently working on gateways between DICOM with EDIFACT, and HL7 as an extension to the DICOM standard.

3.3. General Purpose Imaging Tools

Many image processing tools are available on the market today, together with many public domain and shareware products. This raises the question: "Why should we develop something new for medical purposes?" Still, there are several reasons to do so. General purpose software does not support image formats and protocols such as DICOM, and there are no interfaces to HIS and RIS. The second reason is that they are not capable of handling the additional alphanumeric information (e.g., demographic patient data). Another point is that they do not offer the domain-specific functionality in radiology. MRI and CT images typically have a pixel depth of 12 bits, which is unusual for general image processing tools. Domain-specific image manipulation functions are level/windowing, measurements of length, area, angle, and density in regions of interest (ROIs). What they do not support is data protection and security.

3.4. Medical Imaging Workstations

Special-purpose medical imaging workstations overcome the drawbacks of general purpose tools. Many medical imaging workstations have been developed in the past [38-45]. They are typically based on PCs or UNIX workstations. Most of them have been designed to work in a PACS context. They are able to handle medical image formats and protocols and can be integrated in the environment of radiology or even the entire hospital [19]. The most important drawback of many imaging workstations is that they are designed as an additional console for MRIs or CTs, where several modalities can be displayed on the same screen. The integration in HIS/RIS is missing in most of the cases and, indeed, in most PACS systems.

From the functional point of view, these workstations are operating with special tools to handle medical images. This can be useful for radiologists, but the clinicians in the wards do not need such image-processing tools. They need an overall view of all patient data including, e.g., reports, lab results, biosignals, and images. The clinician will not be able to work with special tools for all types of data. This would mean that he or she has to acquire special knowledge on an image processing tool with perhaps more than 100 image-processing functions. The physician needs an integrated multimedia toolset which directly supports his medical tasks.

3.5. Integrated Health-Care Professional Workstations for Image Processing

Integrated clinical workstations are oriented toward a complete view of patient data, at the same time allowing consulting physicians to have access to the full range of data. An example of such a system is the DHCP imaging system which has been developed at the Department of Veterans Affairs in Washington D.C. [44-46]. A discussion of different ways to integrate medical images into hospital information systems can be found in [44].

The construction of such systems is a very complex task as they depend on the local situation of the hospital, the needs of the single wards, and even the physicians and nurses.

Only a small number of hospitals will be able to pay for the development of such complex applications which match local needs. New methods of software development have to be used for a feasible and inexpensive construction of such systems. One important approach to reach that goal is to use tools for the computer-aided construction of software.

3.6. Software Engineering Tools

Software engineering approaches have to be used to construct distributed client/server applications for integrated information systems in the hospital [47,48]. The HELIOS Software Engineering Environment (SEE) [49,50], which was developed with the support of the European Commission as an AIM project, is one example of how software engineering approaches in combination with object orientation can contribute to integrated medical applications in the hospital. The main idea of HELIOS is to re-use existing software objects to configure individual software solutions. The resulting software takes advantage of existing services for specific tasks, such as natural language understanding [51], decision making [52], or image processing. All software components are distributed in a local network and communicate with each other via object-oriented messages over the HELIOS Unification Bus [53]. The interface to HIS/RIS/PACS and other information sources is handled by a medical connection service [54]. One important set of services (in the context of imaging) are the Image Related Services which are completely integrated in HELIOS [55,56]. It is possible to create special integrated multimedia applications which are designed for the individual, task-oriented needs of physicians with the help of such an environment.

3.7. Example of an Integrated Application

A prototype of an integrated medical application which is task-oriented and not merely a loosely coupled set of tools is ARTEMIS [57], which has been built in the framework of the European HELIOS project by means of the HELIOS Software Engineering Environment [50]. The application is intended to manage information about hypertensive patients and, in particular, the retrieval and display of administrative, clinical, and biological data, as well as the display and analysis of digital angiography images and medical reports. The objective was to show how the developer can use, customize, and organize the services provided by HELIOS. A particular focus was set on re-use strategies and integration during the development process. This prototype illustrates how the distributed architecture of such systems can be built and how it works.

3.8. Teleradiology Systems

The motivation for teleradiology systems is to reduce film costs, patient transport, and travelling of radiologists. The quality of health care can be improved through faster diagnosis and by remote experts who can be consulted in complicated cases. Another advantage could be the reduction of costs through resource sharing of expensive equipment and radiologists (e.g., during night shifts). It is also possible for radiologists to diagnose images after office hours from a computer at home. The diagnostic and therapeutic processes can be speeded up as less time is needed to send medical images to other treating physicians. This can result in shorter patient stays in the hospital, which is an important economic issue [58].

Many telemedicine projects are currently running all over the world, e.g., in the USA, Scandinavia, and Germany. Some examples are given in [59-63]. The status of telemedicine in the USA of 1994 has been described by Grigsby [64]. Many of the systems today use ISDN telephone lines with a transmission rate of 64 Kbit/s per channel, which is relatively economical. Live video images of high quality can, however, not be transmitted in real time on single ISDN lines. Thus, images are usually transmitted off-line before the teleconference [63]. More powerful links are the T1 links in the USA with 1,544 Mbit/s, or asynchronous transfer mode (ATM) links with 34 up to 155 Mbit/s which allow real-time transmission of video [60]. Costs are the major drawback of ATM.

3.9. Medico-legal Aspects

A medico-legal problem regarding teleradiology and teleconferencing is the reimbursement of expenses from health-insurance institutions in the case of interpretation and reporting of medical images sent from a radiology department by teleradiology [64]. This reimbursement must be officially and legally sanctioned. The confidentiality and security of medical images is one of the major medico-legal issues [14]. Furthermore, authentication of the sender and integrity of the data have to be guaranteed. Possible solutions depend on national laws. The legal aspects pose problems for international cooperation, as the laws for data protection and security vary dramatically from "no regulations" (e.g., Italy and Greece) to very restrictive laws (e.g., in Germany).

There are emerging standards which provide a sound basis for the development and implementation of security concepts. The European Union is supporting an initiative for evaluating the security aspects of systems. In ITSEC, security criteria are described [66]. An associated evaluation manual, ITSEM, is also available [67]. Both these EU publications are compatible with and even extend the concepts suggested by the U.S. Department of Defense in the TCSEC "Orange Book" [68]. The German "Bundesamt für Sicherheit in der Informationstechnik" (BSI, Federal Bureau of IT Security) in Bonn publishes an IT Security Manual [69,70], which adopts the concepts described in the EU publications. The proposed security concept has been established and realized in the German teleradiology system MEDICUS [63,65].

3.10. Hardware, Software, Client/ Server

Clinical workstations for image processing are typically based on high-end personal computers running MS-Windows or Windows 95. The available INTEL processors 486 and later can be used for image processing tasks. UNIX workstations are more powerful and also more expensive. High-end PCs and workstations are comparable in price and performance. However, the operating systems of workstations offer more security and flexibility thanks to their multiuser and multitasking concepts. Connectivity is also easier under UNIX than on PCs running Windows [71]. A useful compromise for the future might be LINUX on PC hardware which combines both the low price for the equipment and a better (and cheap) operating system.

The most important hardware aspect is the choice of the monitor for image display. The purpose of image presentation plays an important role. Three different purposes can be identified: reading, presentation, and illustration. If the radiologist displays the images for reading, he or she needs the best quality regarding resolution, size, and luminance. Therefore, similar monitors have to be used as they are connected to the imaging modalities themselves. If the images are presented to other physicians/clinicians after the diagnosis for pure informational purposes, the demands are less high. A good 20-inch workstation monitor can be used in this case. Cheap PC monitors can be used when the images are used for illustration purposes only.

The client/server approach [72-77] seems to be the best way to implement integrated workstations today [48,49,78,79]. A yet unsolved problem is the realization of the layer between client and server: the middleware [80]. An object-oriented approach has been used in the European HELIOS project to let the distributed software components talk to each other [49]. The common object request broker architecture CORBA of the Object Management Group OMG may become a possible future standard [81].

3.11. Medical User Interfaces

Intensive efforts to introduce increased computer support in health care delivery units have not always resulted in increased efficiency. On the contrary, high developmental costs, inefficient systems, and low acceptance are problems commonly encountered. One important reason for this is that the design of the system, and especially of the computer interface, often is not adapted to the specific demands and requirements of the health-care environment. To be efficient, and to be accepted by skilled health-care professionals, the information system must support and not hinder their main focus: the competent care and management of patients [82].

The design and implementation of efficient user interfaces is a prerequisite for successful introduction of computer support in health-care wards. Design principles must be based on a thorough understanding of the cognitive aspects of human-computer interaction [83], as well as on detailed knowledge about the specific needs and requirements of health-care professionals [84]. A domain-specific style guide [85] for the design of medical user interfaces has, for instance, been developed in Sweden [86]. The style guide defines detailed design guidelines together with a set of interface elements specified for the ward domain.

4. Where Do We Go from Here?

The described shortcomings of PACS were due to the non-availability of appropriate computer technology and the considerable costs. Today, this technology is available, the computers are much faster with larger storage capabilities, the software leaves proprietary islands, the communication between computers is established, and the costs are reduced by several orders of magnitude. These accomplishments are not yet implemented in a medical environment. Some people believe that all these advantages now only need to be introduced into a clinical environment. We have only just begun to understand that this is not the case. The basic tools for image processing in general, the storage and retrieval of data in general, and the communication of computers in general are feasible and available. The medical application, however, still needs to be implemented.

After the distributed, isolated workstations had been connected, further important progress was made through a widely available operating system: UNIX (and its derivates). Another push came from the standardized communication protocols. The workstations are now integrated in an open, distributed and interconnected concept.

Even at present, progress made in medical image processing during the last 15 years, is only poorly present in clinical routine. Image processing was not a priori developed for medical applications, and it has proved difficult to develop useful systems for the support of diagnosis and therapy planning. CT and MRI workstations barely allow control of the image production itself.

Real medical image processing workstations are just now being introduced in large radiology departments. The reactions in the medical environment are hesitant. The main shortcoming is the fact that the programs and procedures were developed by computing experts including specialists for image processing and artificial intelligence. The systems are not sufficiently attuned to the physician's needs, interests, and abilities. The next generation of medical image workstations must be designed starting from the medical questions and integrated smoothly into medical protocols. In addition to technical issues, we need to care for man-machine interaction, including ergonomic, psychological, and perceptional aspects.

5. Conclusion

A massive and bidirectional dialogue is underway between computer scientists and developers on the one hand, and medical partners on the other hand to improve the systems. Our job is not only to improve the existing clinical routine by better, faster, and cheaper systems, but also to develop and exploit the new possibilities of the "information age". We hope that the technology-driven improvements in health care result in more attention and care for the patient.

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