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The future of PACS in healthcare enterprises

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ABSTRACT

Picture Archiving and Communication System (PACS), which was originally designed as a tool for facilitating radiologists in interpreting images more efficiently, is evolving into a hospital-integrated system storing diagnostic imaging information that often reaches far beyond Radiology. The continuous evolution of PACS technology has led to a gradual broadening of its applications, ranging from teleradiology to CAD (Computer-Assisted Diagnosis) and multidimensional imaging, and is moving into the direction of providing access to image data outside the Radiology department, so to reach all the branches of the healthcare enterprise. New perspectives have been created thanks to new technologies (such as holographic media and GRID computing) that are likely due to expand PACS-based applications even further, improving patient care and enhancing overall productivity.

1. Introduction

Picture Archiving and Communication System (PACS), which was originally designed as a tool for facilitating radiologists in interpreting images more efficiently, is evolving into a hospital-integrated system storing diagnostic imaging information that often reaches far beyond Radiology. In the last decades, PACS technology has supported the expansion of new tools for assisting diagnostic imaging, such as teleradiology (offsite interpretation of medical images) and CAD (Computer-Assisted Diagnosis). This evolution has been paralleled by workflow reorganisation in Radiology departments and has facilitated patient data management in hospitals. There is evidence that the change in workflow associated with the use of PACS has resulted in increased efficiency of technologists by 20–60% and of radiologists by more than 40% [1].

A significant PACS implementation barrier has traditionally been system cost. Unfortunately, most savings are "soft" and not directly traceable back to the Radiology department itself. For instance, when a PACS investment is competing with the acquisition of a new digital modality (such as CT or MRI) which immediately generates new revenue upon installation, it is sometimes difficult to make a good business case. In fact, the economical and organisational impact of PACS has been underestimated for long time. This attitude is expected to change in the near future due to the gradually increased number of patients (favoured by the global ageing of population) associated with a decrease of healthcare technologists and medical staff [2,3], which will likely prompt the further development and diffusion of information technology applications within the healthcare enterprise.

2. The hub of the new medical enterprise

Attempts to make imaging data available to anyone, anywhere and at any time have been among the most important initiatives established at a worldwide level in order to meet the needs of healthcare enterprises.

A key factor to fully harness the benefits of PACS is its integration with other systems and workflows already present in the hospital. The recent Integrating Healthcare Enterprise (IHE) initiatives emphasise the integration aspect of PACS implementation. Unfortunately, many current PACS systems exist like independent islands outside the information stream of healthcare organisations [4], and in most cases such systems simply enable PACS workstations to receive, send, and backup DICOM files manually. In other terms, most current PACS systems almost never support full communication with administrative and clinical patient databases or, generally speaking, with the rest of the Hospital Information System (HIS), which is typically heterogeneous, as it is usually multi-functional and multi-vendor. In particular, getting systems by different vendors to communicate with each other may be extremely difficult. Today, the goal is no longer just to give non-radiological departments access to radiological images ('vertical' integration, i.e. integration at the hospital level across specialties), but to ensure that imaging data is readily available and usable

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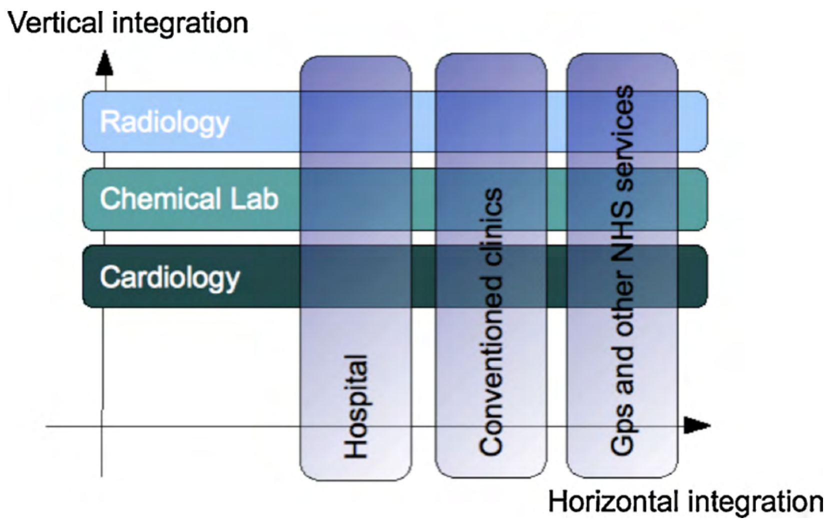

Fig. 1. PACS will be the hub for the 'vertical' and 'horizontal' integration of healthcare systems.

at every possible location within the affinity domain ('horizontal' integration, i.e. integration at the territorial level across healthcare services, including affiliated standalone clinics, referring physician offices, and other structures of the National Health System) (Fig. 1).

The ultimate goal behind merging imaging data with other medical information from nonradiological specialties is to create an entirely Electronic Medical Record (EMR) for every patient that should be capable of being transmitted anywhere. This new scenario will further lower total operating costs and increase the quality of healthcare and clinical efficiency, thus allowing clinicians to spend more time with patients and radiologists to perform more examinations in less time with fewer errors.

One huge advantage of being able to freely share and exchange PACS files is the possibility to use them remotely and to give non-radiologists an easy and unlimited access to clinical images. For example, today a growing number of interventional facilities have the technology to display multimodality image data, such as those from MRI, CT, and nuclear medicine studies. Automation, functional integration with diagnostic departments, and digitalisation are the key features of tomorrow's interventional facilities and will help increase the quality of care, especially in the case of emergency departments, in which the possibility to receive patient data in a few seconds may be crucial for proper patient management. Clinicians will be provided with the tools to easily and quickly communicate across specialties, such as Voice Over Internet Protocol (VoIP) and Instant Messaging Systems (IMS), thus enhancing interdisciplinary cooperation.

The idea that PACS may become the hub of the medical enterprise would have seemed weird just a few years ago, but current technology is moving into this direction. As a centralised repository for all imaging data, PACS is actually regarded as the natural control centre for making images available anywhere within the affinity domain. The requirements that any new PACS implementation should fulfil in order to really configure as the hub of the new medical enterprise have already been the outcome of EuroPACS 2004 [5,6] Fig. 2. The vision of PACS as the hub of the new medical enterprise is supported by reports [7–9], showing that Radiology PACS market is expected to grow in the next 5 years at a CAGR of 3.7% in USA and of 8.4% in Europe.

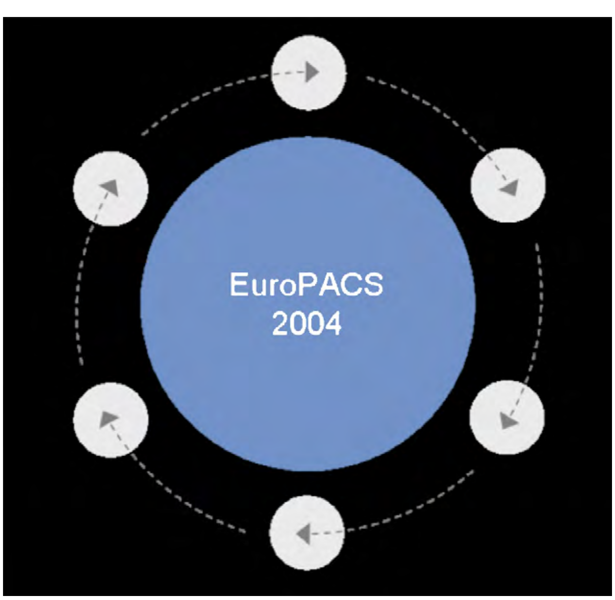

Fig. 2. EuroPACS 2004 set standards for PACS as the hub of the new medical enterprise.

3. PACS: the multimedia component of the future Electronic Medical Record

In recent years, there have been major changes with great impact upon image acquisition, storage requirement, display and network requirements. When introduced initially, many healthcare units could not afford PACS due to their expensiveness. However, rapid advancements in technology and the development of communication standards and open architectures have led to a dramatic cost reduction, enabling many institutions to implement PACS in order to ensure a more efficient workflow with shorter waiting times, faster and often more confident diagnosis, and overall higher productivity. Recent technological advances include the development of dedicated web portals and Virtual Private Networks (VPN) in order to improve viewing and post-processing of DICOM images, which has been enabled thanks to the growth of web utilisation and wireless technology. In the last decade, an almost full integration of PACS with Radiology Information Systems (RIS) has been achieved, and one interesting application under development is structured reporting, in which the PACS ability to manage multimedia data will likely play a major role.

The core part of PACS functions will continue to be devoted to imaging informatics, although increasingly more sophisticated

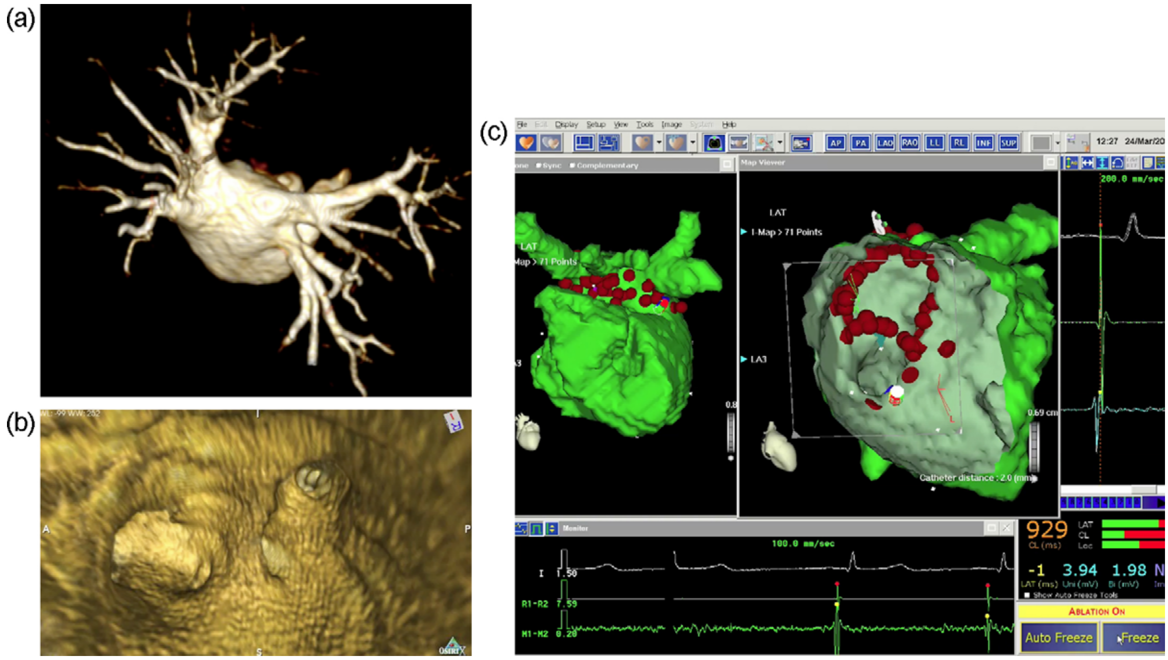

Fig. 3. Real-time MRI-guided percutaneous ablation of atrial fibrillation. Volume Rendering (a) and Virtual Endoscopy (b) reconstructions give the interventional cardiologist a realistic depiction of the left atrial anatomy, and (c) real-time image fusion between pre-procedural MRI and intraprocedurally obtained electrophysiological map allow him to safely navigate inside the left atrium, with a reduced risk of interventional complications and a dramatic decrease of radiation exposure due to reduced need for fluoroscopic guidance.

technologies are needed on a routine basis, such as Computer-Aided Detection (CAD) applications or post-processing of multidimensional data.

Dedicated plugins can be launched from PACS stations, that allow to perform CAD on image datasets (e.g. CT colonography [10], lung CT [11], and mammography [12]) that can be retrieved online in DICOM format from the PACS network. The online availability of such tools can be advantageous in terms of increased diagnostic confidence, as it can help radiologists to detect lesions on the same workstation used for 2D image reading and reporting. Besides improving diagnostic accuracy, PACS-embedded tools can also lead to substantial cost savings, as they can replace dedicated offline workstations [13].

Modern PACS systems already allow to perform, alongside basic 2D reading of cross-sectional images, 2D and 3D image reconstructions of datasets composed of thousand of DICOM images. The ready availability of such advanced post-processing capabilities have partly revolutionised the way CT and MRI series are read, as the regular use of 2D and 3D reconstructions can improve the radiologist's diagnostic accuracy and enhance the communication between radiologists and other specialists [13]. In particular, surgeons and interventionalists usually find it more immediate to view 3D images (which provide a more realistic view of the patient's anatomy), that in some cases allow to effectively synthesise the analytical information contained in hundreds or thousands of thin-slice 2D cross-sectional images (Fig. 3) [14,15]. Another, more advanced possibility is 4D imaging, based on the visualisation of 3D images over a time course, which is useful, e.g. in cardiac radiology to evaluate the function of the myocardium or the cardiac valves. Beyond 3D and 4D, a shift in the near future toward 5D data – for instance, metabolic data by means of radiolabelled tracers – for a new generation of diagnostic procedures is expected, and advanced PACS systems should be able to handle this kind of information [16].

4. Advanced technology attains improved PACS performance

4.1. Holographic PACS for enhanced speed and storage

Holographic media are an emerging technology which could overcome the physical barriers to approaching data storage through a powerful combination of high storage transfer densities and fast data transfer rate, thus replacing conventional magnetic and optical drive-based storage systems [17,18].

Holographic storage differs from other recording technologies in (i) its capability to offer massively parallel recording and reading of data rather than the serial approach of traditional methods, and in (ii) its efficiency to exploit the entire thickness of a recording medium rather than just its surface. Instead of laying down the data on the surface layer of the medium as in conventional digital recordings, holography uses lasers and light to record data in three dimensions. Unlike conventional technologies that record data sequentially, holography allows a million bits of data to be written and read in parallel with a single light beam [19]. This enables significantly higher transfer rates than current optical storage devices.

Radiology is certainly the major area that will see its workflow improved by holographic PACS, but there will be other specialties, like surgery, which could benefit from it as well. Digital holographic technology could enable neurosurgeons to preoperatively plot their way to tumours [20], just as orthopaedic surgeons can simulate placement of pedicle screws prior to performing surgery, with the potential to improve treatment effectiveness and patient safety.

Holographic technology is still too immature to determine what the actual cost per gigabyte of storage will be, even if comparative data suggests that the cost for new holographic media is vastly better than current expensive storage technologies (i.e. data tape, video tape, and hard disk drives). Nevertheless, the deployment of

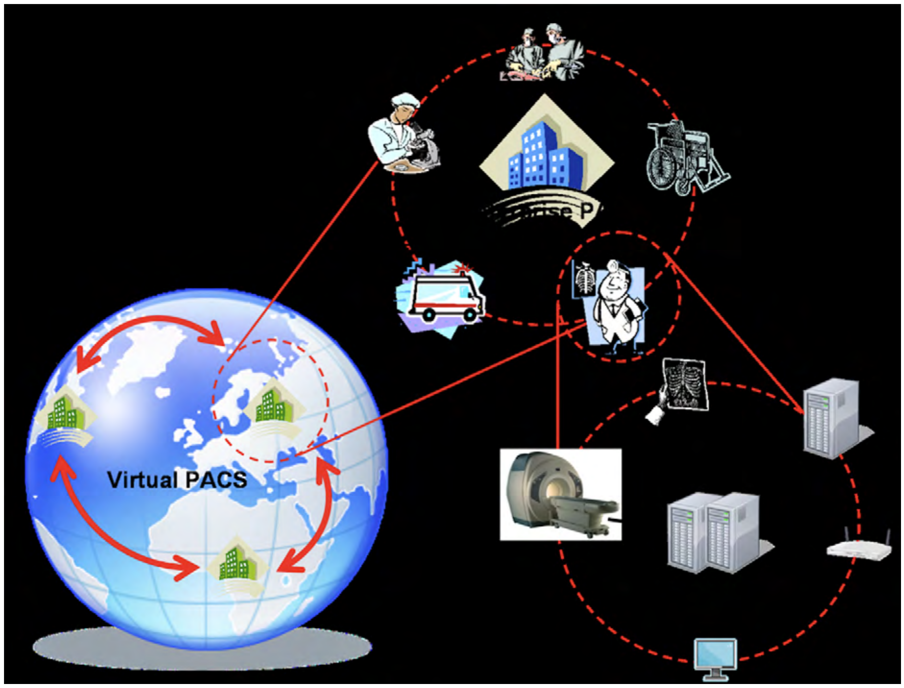

Fig. 4. The future of PACS will consist of different implementations at three hierarchical levels: single department through new storage technologies (holographic PACS), healthcare enterprise through vertical and horizontal integration among specialties and departments (enterprise PACS) and, finally, cross-enterprise through scalable GRID technology (virtual PACS).

holographic PACS (i.e. a holography-engineered PACS) could be a first step towards the photonic revolution of information technology in healthcare, in an attempt to meet the performance needs of healthcare enterprises [21–23].

4.2. Virtual PACS and GRID technology: a vision for the future

In Radiology departments, it is still a challenging task to share data across institutions despite the widespread adoption of the DICOM standard. Too often the community relies on simple, but inefficient means of sharing data, such as burning CD and sending them by mail. This is largely due to the lack of fast and secure mechanisms that support interactive access to data resources from outside institutional firewalls. As a solution to this problem, a mechanism for standardised, efficient, and secure access to geographically distributed resources of imaging data has recently been proposed in the literature under the name of Virtual PACS [24].

Virtual PACS federates multiple remote data sources and presents them to a DICOM client as a single virtual resource. Data sources can be native DICOM sources (such as DICOM PACS servers), as well as non-native DICOM sources (i.e. sources of DICOM objects which do not support DICOM messaging and may store images on disk or in databases). This federation of PACS archives serving cooperative backup archives for one another can effectively be obtained using GRID technology. In this design, only a small fraction of the PACS data archive resource is needed from each federated member (Fig. 4).

GRID computing has emerged as a viable solution to address these challenges [25,26]: using GRID-enabled software, healthcare enterprises can share geographically dispersed resources, including software, applications, and data storage and processing platforms. GRID computing is not new within the scientific community (it grew out of the work of many computer scientists in the 80s and 90s) but only recently the medical imaging community has begun to explore its possibilities.

The potentialities of GRID computing to create healthcare benefits are tremendous: it has been defined in the literature as 'an environment that facilitates flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions and resources' [27], and its applications include teleradiology services, distributed and remote image processing and analysis, quality assurance and research, and clinical data mining.

4.2.1. GRID computing for advanced image processing

For a typical client-based online PACS architecture, a traditional approach to advanced image processing would involve the collection and transfer of image data to a central location. The rationale of this strategy is to tap the computational power of central high-end servers to perform heavy-duty image processing algorithms, allowing clients (which are usually cheap, low power computers) to accomplish light tasks, such as image viewing and reporting. However, while high-speed networks are often necessary for such remote resource use, they are far from sufficient: remote resources are typically owned by others, exist within different administrative domains, run different software and are subject to different security and access control policies. Moreover, the increasing size of DICOM images (due, for example, to the widespread availability of multislice CT scanners producing thousands of thin slices) increases the risk of bandwidth saturation, thus limiting the network access of multiple users and potentially slowing operations to an unacceptable level. GRID systems and technologies provide the infrastructure and tools to solve these kind of issues and make large-scale, secure resource sharing possible and straightforward. With the use of GRID computing, widely distributed data are easily shared and accessible for development and evaluation.

GRID computing represents the latest technology in the evolution from the familiar realm of parallel, peer-to-peer and client-server models. A GRID infrastructure would provide more functionality than the Internet on which it builds, providing new services that address end-to-end issues of authentication, resource discovery and resource access. While Internet and web tools include browsers for accessing remote web sites, email programmes for handling emails, and search engines for locating web pages, GRID tools are concerned with resource discovery, data management, scheduling of computation and security.

4.2.2. GRID for CAD

The future will see PACS systems fully equipped with the most advanced state-of-the-art technology for image analysis. One of such most promising tools is CAD, which can be technically thought of as a computer vision system that uses advanced pattern recognition and image analysis techniques to automatically detect medical abnormalities. There is a growing body of literature supporting the ability of CAD systems to increase diagnostic accuracy when used in combination with human readers [28,29]. However, the additional time required for use of CAD systems suggests a need for the development of modifications in workflow and in the way CAD is used to streamline the image interpretation process.

Current commercially available and experimental CAD systems operate on local data sources and in most practices, a CAD system from a single vendor is used at a specific location. As diagnostic imaging data obtained with CT and MR imaging increase in spatial and temporal resolution as well as in overall complexity, the amount of data stored per patient also increases dramatically. Latency in data transfer across the healthcare enterprise for remote image review increases with increasing data size, thus adversely affecting the user's ability to dynamically interact with databases. GRID technology can greatly increase the accuracy and speed of image analysis by sharing data as well as computational resources.

Indeed, GRID computing is particularly well suited to complex and computationally demanding applications in medical imaging. As opposed to current commercially available CAD systems, GRID-CAD can integrate into a GRID framework different CAD programs by multiple vendors, thereby creating an infrastructure that allows invocation of multiple CAD algorithms in parallel on one or more image datasets [30]. For example, there is the intriguing possibility to use CAD applications by different vendors in a cooperative manner, so to enhance, e.g. the performance and accuracy of lung nodule detection in a single image dataset [31].

4.2.3. GRID for efficient data storage

PACS are widely used in hospitals and are considered mission-critical for around-the-clock daily clinical operation. Whereas failure of individual workstations or acquisition components will affect data workflow in the local PACS branch, failure of the main PACS archive server may cripple the entire PACS operation, thus posing a serious threat to the activity of a Radiology department. Unfortunately PACS technology, despite its dramatic evolution in the last decade, still remains weak in the area of clinical image data backup. Current solutions are expensive or time-consuming and the available technology is far from being foolproof, and many large-scale PACS archive systems may still experience downtime periods of hours or days, with the risk of permanently losing patient data in the event of severe damage. Therefore, with the increasing presence of fully filmless hospitals, it becomes more and more crucial to provide solutions to protect the PACS data.

By using GRID technology, the above limitations would be alleviated for the following reasons:

(1) by applying a GRID computing architecture to a DICOM environment, a federation of PACS can be created, allowing a failed PACS archive to seamlessly recover image data from the others;
(2) by distributing redundant copies to different storage sites, a GRID implementation would avoid the risks of data loss connected with a single-point failure in a non-distributed environment;
(3) by implementing dedicated network services, the GRID technology would enable resource optimisation by matching network availability with the specific task to be performed.

5. Conclusions

The goals of all Radiology departments are similar: we all want a system that optimally supports the patient–clinician–radiologist relationship. PACS can be defined as a system that achieves this aim by facilitating image diagnosis, potentially leading to a more prompt and effective management.

PACS has traditionally been an important tool in Radiology departments, but now a steady increase in its use is also occurring in non-Radiological facilities. As long as this process of longitudinal and horizontal integration within the healthcare enterprise proceeds, hospitals will increasingly be facing the problem of inadequate storage resources. Holographic storage technology applied to PACS archives appears to be a promising approach to solve these issues. GRID technologies will likely aid the creation of virtual hospitals, and are becoming increasingly relevant in modern healthcare enterprises, as they have the potential to boost the power of PACS systems in an efficient way, by improving handling of image storage and processing capabilities.

Conflict of interest

No conflict of interest exists for any of the authors.

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