PACS - Next Generation

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ABSTRACT

In this paper, we propose a web-based framework for traditional PACS that has the potential to revolutionize the management and display of medical images while simultaneously decreasing the cost of deployment. Specifically, we demonstrate that all the tools to replace traditional PACS are finally available to make the transition to the internet. In addition, web-based solutions offer capabilities that go well beyond traditional PACS.

Keywords: PACS, Cloud Computing, Web, Internet, DICOM, Medical Imaging

1. INTRODUCTION

Technologies, such as PACS, that is widely used in medicine, are not easy to displace. But, the rapidly evolving landscape of the internet is quickly providing compelling pathways to become the dominant repository for the management and display of medical images. Such technologies can be readily embraced by institutions in developing countries where the budget to invest in the high cost of traditional PACS is frequently considered a luxury. As a result, the potentially large uptake by health-care facilities around the world will propel the future of a world where the role of a traditional PACS can be safely minimized without any loss of patient care. In fact, as we will see the newer technologies will simultaneously significantly reduce capital expenditure and operating costs while improving health-care outcomes.

Next generation of PACS should provide the ability to transfer images reliably, securely and quickly over a network together with the ability to view them without time delay even for large images over the cloud. Typical PACS over LAN were not designed for streaming multi-media images and video. On the other hand, a cloud based architecture using standard protocols (streaming, SOAP, etc.) can leverage widely available infrastructure. Specifically, large images can be automatically broken-up on the server and streamed over the network to the user. Unlike CAD viewers, streaming images and video to view on a web browser can be made with standard technology thereby delivering a superior user experience. Here a zero footprint viewer that can meet all these requirements, without plugins and without the user having to explicitly unzip/uncompress images is demonstrated. This architecture naturally lends itself to secure communications over the cloud without the need for costly VPN.

Moreover, PACS as it stands today is primarily a "pull" model in which an explicit request for viewing images is made by healthcare professionals. A web-based architecture, offers the ability to embrace a "push" model that can automatically send alerts to patient care providers when new information indicates abnormalities, something that cannot be easily achieved with traditional LAN architectures.

The path to perform additional tasks such as image segmentation, processing, 3D renderings, etc. that require CAD based systems, on web browsers is also illustrated here.

The need to evaluate the future of PACS has an heightened sense of urgency. According to the 2011 CapSite report on PACS replacement,[1] 52% of PACS in US hospitals are more than 5 years old. Thus, hospitals will soon be faced with expensive decisions on investing in new, but traditional PACS solutions, or whether they should invest in newer, and cheaper but equivalent technologies. An incorrect decision could result in not only huge financial losses but also isolate the hospitals from network-based communications and inter-operability with other institutions aroud the country and the world.

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In this presentation, we first review the key features of a traditional PACS solution. We then highlight the equivalent PACS functionality in a web-based solution. Finally, to illustrate the increasing viability of a no-hardware/no-software download/only-browser type of solution, we discuss in more detail the architecture of some of the equivalent web-based functionality.

2. TRADITIONAL PACS

Traditional PACS functionalities can be classified as follows:

1. Image Management and Display
   (a) Refers to the ability to view DICOMs of different modalities on a workstation
2. Communications
   (a) Refers to the functionality whereby systems can query and retrieve medical images from PACS
3. Administration
   (a) This is a broad category that encompasses a variety of features such as
      i. Organization of medical images for a patient, including historical images
      ii. File system storage for the images
      iii. Secure access to the workstation

2.1 Traditional PACS Limitations

Despite the wide-ranging success of PACS, there are serious shortcomings with traditional PACS. These primarily stem from the way that PACS are typically configured. As a result, the following capabilities are often difficult, and in some instances, impossible to find in traditional PACS:

1. Image Display Issues
   (a) Lack of standards based streaming protocols for reading data made available over time means that images have to be completely downloaded before they can be viewed, or vendors use proprietary approaches that cannot be guaranteed to work over a large range of images. For large images, this latency can be an annoyance.
   (b) Application vendors have often built modality-specific workstations. This contributes to their high capital expenditure and on-going maintenance costs.
2. Communications Issues
   (a) PACS typically operate on LANs that are hard to reach from outside. Thus, it's difficult to obtain second opinions from other physicians, especially those that may be in different institutions around the world. But there is a bigger problem lurking here: even if, somehow, access to the LAN is achieved, the issue of how an outsider can gain access in a secure manner to the relevant image still remains.
   (b) To retrieve images from another PACS workstation, the DICOM standard has specified operations, the DICOM Message Service Element (DIMSE).[2] These include the Composite Operations such as C-FIND and the Normalized operations such as N-Create. Even though these operations are well defined, there are still inconsistencies between implementations across vendors. These often manifest themselves when images from different modalities are requested, and the target PACS has only a partial set. In such cases, the response from the target PACS is not consistently implemented across different vendors resulting in errors.
   (c) Finally, it's important to note that while the DICOM standard specifies the communication protocols, these are not widely known in the larger computer development field. Consequently, any development, modifications or enhancements will always take longer and cost more than comparable efforts using mainstream technologies.

3. Administration Issues

   (a) Lack of a relational database increases the complexity of organizing and managing patient information coherently. Consequently, retrieving historical patient studies, say, for comparison purposes is challenging thereby compromising patient care.

   (b) Traditional PACS is a hardware centric solution with their concomitant problems:

      i. With the large number of images that have to be taken per series, the memory needs to be carefully managed so that the system always has adequate storage space. This administration leads to increased costs but also to the human cost of monitoring and procuring additional storage when warranted.

      ii. Securing access to PACS so that only authorized personnel are able to view them is, again, often achieved through physical rather than software means. Workstation access is limited by restricting access to the rooms that they are placed. This comes at the cost, however, of making them immobile - users have to physically go to workstations to view images.

      iii. Being hardware, institutions have to ensure that they are well maintained. This adds to human monitoring costs.

      iv. PACS are an expensive proposition. Their high costs are prohibitive for institutions in developing countries.

3. FUTURE OF PACS - WEB-BASED

A web-based PACS is a collection of technologies that together make it viable proposition to replace traditional PACS. The promise,though, of a web-based PACS has only recently become viable. While there has been much talk about moving PACS to the internet over the past few years, there were challenges that till recently made such a transition highly unlikely. Specifically, the following capabilities are well addressed in a web-based solution:

1. Securing access of medical images to authorized personnel

2. Use of a relational database to manage the organization of medical images

There are others, such as the ability to display DICOMs on a web browser - critical for any traditional PACS replacement, that till recently were sub-optimally addressed. Previously, DICOM files were converted to standard format natively recognizable by browsers, such as JPG or PNG. While this conversion made it possible to view DICOMs on browsers, image processing capabilities were lost.

The recently introduced HTML5 standard made it possible to view DICOMs on web browsers without the need to first convert to lossy formats such as JPG or PNG. (While HTML5 was available earlier, it was in "candidate" state. Thus, while browser providers such as Google (Chrome^{TM}), Apple (Safari^{TM}) and Microsoft (Internet Explorer^{TM}) provide limited support of HTML5, there was no guarantee that those would continue to be supported in the future. Consequently, it would be difficult for vendors to build applications with the risk that their development efforts may be laid to rest. With the introduction of HTML5 as an official "Recommendation" from the W3 organization,[3] however, the status is assured.

Furthermore, the related specification for cascading style sheets (CSS3) allows images to be easily reflected for comparison studies when analyzing, say, breast mammograms.

Together with the emergence of HTML5 being an official standard and the evolution of cloud computing, a web-based approach to PACS becomes an attractive and implementable approach. For each of the three broad categories for PACS capabilities introduced earlier, a web-based approach offers equivalent or superior advantages. Furthermore, this approach offers additional capabilities that could not be provided by a traditional PACS solution:

1. Image Management and Display
   (a) Arguably, one of the most important technology innovation that makes a web-based PACS a viable proposition is HTML5. HTML5's `<canvas>` tag provides the ability to read image intensities specified in bytes and display on the browser. With this capability, the image bytes in a DICOM file can be displayed directly on a web browser without the need for the user to pre-install any plug-ins.
   (b) Ajax (Asynchronous JavaScript And XML) is a group of interrelated Web development techniques used on the client-side to create asynchronous Web applications. Specifically, with this technique, a web browser can do the following:
      i. In a multi-frame series, the entire series doesn't have to be loaded before the user can start viewing the images. Instead, the server can be configured to send just a handful of the first few images in the series. Then, using AJAX, the client browser can request additional images as the user starts scrolling through the images. This partial loading of images means that the user can start viewing images almost in real-time.
      With HTML5, AJAX has become even more powerful as it provides support for support uploading/downloading binary data, critical for downloading binary DICOM file and displaying the image data specified therein. We call this approach the "inter-frame AJAX."
      As a result, the user can scroll through the frames of the series without causing any browser refresh and offering a seamless way for the user to scroll through the images.
      ii. While the previous use of AJAX decreases latency by downloading just a handful of frames instead of the entire series before the user can start viewing them, another related technique can be applied in conjunction to decrease latency even more, making the display of images seem almost instantaneous. In this case, the web server would open the DICOM file requested but instead send only a fraction of the bytes (that is, every other nth byte) to the browser. This would load the image almost instantaneously albeit at a lower resolution. But, the lower resolution would not affect the image being viewed at full size. Then, as the user spends a few seconds looking over the image, the additional bytes are sent so that if the user chooses to zoom in, there would be no loss of resolution. We call this approach "intra-frame AJAX."
      HTML5's Stream API[4] can be used to facilitate this approach.
   (c) To make the web browser a true replacement for Traditional PACS, the user must be able to interact with the image in the same way as on PACS workstations. Here again, with HTML5's `<canvas>` element, the image's pixel intensities can be manipulated by user gestures (touch and mouse moves) and clicks on the browser using Javascript.
   This allows all the standard tools such as Window Leveling, Contrast Adjustment, Zooming and Panning to be offered. In addition, measuring tools such as rulers and protectors can also be defined. These tools allow the user to interact directly with the image without having to send anything back to the server.

2. Communications
   (a) One of the greatest concerns of a web-based PACS has been the latency as the user may have to wait before the image can be downloaded before viewed. However, download speeds have increased significantly over the past few years that this issue has been rendered moot. Nowadays, images can be downloaded to even handheld devices in fractions of seconds. With streaming capabilities (discussed above), images can be displayed almost in real-time.
   (b) As stated earlier, Traditional PACS can be queried using DIMSE protocols. On the other hand, in a web-based model, there are more options to query and retrieve medical images. However, a fundamental ingredient for all of them is the ability to organize and manage the medical image and related information in a relational database.
   The way these typically work is that as each medical image is loaded into the web-based system the first time, their headers (in binary format) are read by the server and the information stored in relational database tables.

Subsequently, queries for specific medical images are made against the relational database.

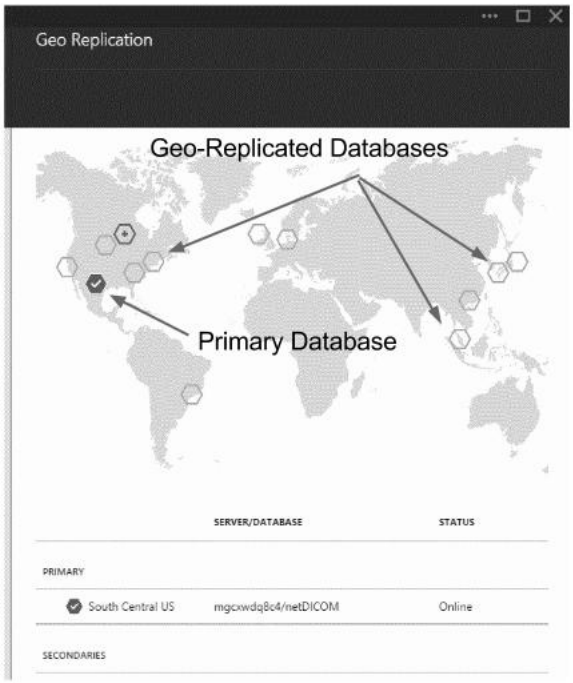

Figure 1. Geo-Replicating Databases in Azure Cloud Services

Internet technologies specify ways in which systems can query each other to obtain information. The predominant technology have been SOAP Web Services and REST APIs. The current trend, though, seems to favor REST APIs.

REST (Representational State Transfer) APIs (Application Programming Interface) are lightweight, maintainable, and scalable web services built upon the HTTP protocol. Just like humans who type in an URL in a browser's address bar to visit a website, a REST web service, called a RESTful service, enables machine-to-machine communications. Provided that external web servers have the proper authentication credentials, they can query the web application and request the data.

What makes RESTful powerful is that the format of the URL together with the information in the body of the request can fully replace the DIMSE operations such as C-FIND. Thus, using standard web technologies, the DICOM communications problem is elegantly addressed.

3. Administration: This set of capabilities cover a miscellany of functionality that are necessary to operate a secure and scalable PACS application residing and operating entirely on the web.

   (a) Cloud Computing: This is a set of technologies that offer a "pay-as-you-go" model. Such an approach is critical for the management of high volume applications such as medical images so that Healthcare facilities only pay for the storage they need. They don't have to provision (and pay) for additional storage just in case they need it. With a cloud-based model, additional storage is automatically provisioned as needed. This ability of cloud services such as Microsoft Azure or Amazon Web Services to offer "elastic" provisioning dramatically reduces the total cost of investment for Healthcare facilities. And, when compared to traditional PACS, this cost advantage is a game-changer.

   Another major advantage of cloud computing over traditional web hosting is that databases are replicated in data centers around the world. This allows facilities to be served from databases that they are geographically closest to. Figure 1 is a screenshot from Microsoft's Azure Cloud Services Dashboard which shows how databases can be replicated in different geographic regions.

   Finally, most cloud services nowadays offer 1-click high-availability, backup, and disaster recovery

solutions. As a result, the entire IT functions for managing a PACS can be completely devolved to a cloud based PACS. (Note of caution: While the promise of a cloud based PACS is attractive, many vendors still haven't got the full picture implemented correctly.)

(b) A major concern with any web-based system is security. Healthcare organizations will be reluctant to cede control of their traditional PACS environment to a cloud service where they have no physical authority over their images and data. However, today's encryption technologies are extremely sophisticated. Storage, as well as transportation (wireline and wireless) channels are secure and free from malicious tampering. Thus, access to a cloud based PACS is safe and secure. And, with cloud based services such as regular backups, disaster recovery, equivalent, or in some cases, superior, levels of infrastructure can be obtained. Thus, the move from a healtcare organization owned network to the cloud is no longer a technical sticking point - rather the challenges are more political and an unreasonable fear of new technologies.

As is well known, the standard way to access services on the web is to first login using an unique username and password over secure channels protected by current encryption methods such as Transport Layer Security (TLS) Version 1 or higher. Nowadays, though, this simple login process can be enhanced and the security made stronger by newer technologies such as Multi-Factor Authentication." In this case, the user would be sent a single use code that would be sent to the user using another channel such as an SMS (text message) or an automated voice call to a pre-registered phone number. The user would need to use this code together with the username/password to gain access to the system.

The username/password together with multi-factor authentication controls access to a pre-registered group of users. However, this process can quickly become onerous if the system is used to grant limited viewing privileges to third party users not pre-registered, such as other radiologists for second opinions, a patient's primary care doctor, etc. Creating user accounts for these users who access the system once or a few times can become an administrative nightmare. However, new standards have just emerged, such as OAuth,[5] an open standard to authentication. Using OAuth, third party users can gain access limited and secure access to HTTP service using their credentials that they have registered with Google or some other healthcare organization. This technology allows

i. Web-based PACS to grant limited access to services such as viewing DICOMs without having to first create accounts. This eliminates the administrative overhead to create and manage third party accounts

ii. Third party users can access the system using their own credentials without but without having to disclose anything to the web-based PACS system.

This process makes it remarkably convenient to share information in a secure manner without compromising security.

(c) Inter-operability: With XML based technologies, such as SOAP Web Services, RESTful services, information can be securely shared across many different web-based systems without manual intervention (that is, Machine-to-Machine communications). With such technologies, hospital systems can transfer patient information, including DICOMs if necessary, to other web-based systems, including a suitably configured web-based PACS. Specifically, using standards such as HL7,[6] clinical information can be shared across healthcare facilities. HL7 v3, however, suffered from a global lack of adoption, especially in the US. Thus, the HL7 body has introduced a new new approach to healthcare information exchange called Fast Healthcare Interoperability Resources (FHIR). With these standards, administrative and clinical information can be exchanged securely and consistently across different healthcare organizations over the internet.

4. Additional Capabilities: These are some capabilities that a web-based PACS can offer which would be difficult or almost impossible to get on traditional PACS.

(a) Email notification: One of the features of web applications that we take for granted is the ability to receive notification and other types of emails from the web application. These notifications can be alerts, confirmations, call for actions, etc. Traditional PACS, because they are on LANs, cannot offer these features. But, a web-based PACS can take advantage of the email capabilities and offer features such as the following:

i. Notification to appropriate group (physicians, etc.) when new images have been uploaded to the system

ii. Alert notifications if new images have not been read by a doctor by a pre-specified time

iii. Ability for a physician to send an email to another physician for a second opinion.

A. The email would not contain any images as attachments. Rather, the email would contain a link that when clicked, the recipient would be asked to authenticate and only then be taken to a page that displays the images. The physician would then be able to read the images, and note their report or opinions.

B. Upon completion, the system would send an email to the physician that requested the second opinion.

(b) HTML Links: : Information in the system can be shared (in secure ways) with other applications. In addition to embedding links in email, links can also be placed in other web documents.

(c) One of the benefits of having a system that resides on a web server is that it provides enormous processing power. As a result, a web-based PACS is not just a repository but an intelligent machine. The following is a list of some of the capabilities that can take full advantage of this:

i. Image processing: While HTML5 provides a `<canvas>` that allows users to manipulate pixels on a browser, server side languages, such as C# and Java™have the ability to open binary image files and access pixel level data. Thus, server-side code can be written that can perform image processing algorithms. Specifically, kernel operations can be performed against the pixel level data for edge detection, digital subtraction between 2 images to highlight differences, etc.
The ability to detect edges can be further enhanced by using different pre-defined kernels for different modalities and organs. (The pre-defined kernels would be stored in the database so that the system would be able to automatically match the most effective kernel based on the header information in the DICOM.
These image processing techniques can be executed in a predetermined sequence, again based on modality and organ, so as the extract potential tumors or other clinically relevant information. Furthermore, based on deviations from normality, email notifications can be automatically configured to be be sent to physicians for prioritized reading of the image. Thus, patient care can be dramatically improved
The edges detected can be stored as image meta-data in the database and super-imposed on the image at the time of display. This information could then be used as a guide to the physician indicating where they should first look.
Figure 2 demonstrates that the browser is capable of running edge detection algorithm. The image on the left is the original DICOM image. The image on the right is the result of executing a basic edge detection algorithm within the browser itself without any plug-ins or pre-installed software.
Conversely, a physician can also manually outline and highlight regions of clinical interests on the browser. Then, these user annotations can also be stored back in the database as image meta-data.

(d) Anonymization of DICOMs: Frequently, medical images need to be anonymized and stripped off all personally identifiable information such as name, DOB, etc. A web-based system can offer two types of anonymization techniques:

(e) The integration of a database offers another tantalizing feature. The IHE "Management of Radiology Reporting Templates"[7] can be stored in the database. Then, when a radiologist wants to write a report, the system can automatically match the information from the DICOM header and then present the most appropriate template for the radiologist. This intelligent template matching that will further streamline the workload of physicians.

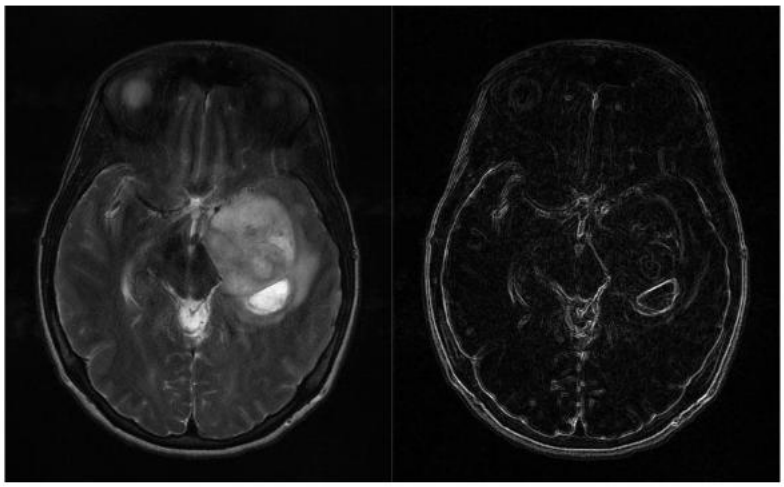

Figure 2. Detecting Tumors using Edge Detection

4. CONCLUSIONS

The next generation of PACS will be driven primarily by advances in technologies rather than improvements in clinical care. There are a myriad of web-based technologies that are just over the horizon and poised to go mainstream in the very near future. These can be effectively harnessed to provide an alternative to traditional PACS. These will, at first, be beneficial in developing countries where the high cost of traditional PACS is a barrier. However, the benefits offered by a web-based solution will propel the drive of traditional PACs to the cloud.

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