Chapter 8
The Design of SkyPACS: A High-Performance Mobile Medical Imaging Solution

Tananan Pattanangkur, Sikana Tanupabrungson, Katchaguy Areekijseree, Sarunya Pumma, and Tiranee Achalakul

Abstract Lack of radiologists is a problem that arises in many parts of the world. Radiologists need to work long hours for multiple hospitals. In order to improve the quality of healthcare, SkyPACS is designed. It is a mobile solution that allows radiologists to work more conveniently. SkyPACS is a low-cost and customizable medical image viewer that can be used for prognosis. The solution is designed to be an assistive technology with the focus on simplicity, flexibility, and user experiences. The architecture of SkyPACS is designed based on service-oriented Model-View-Controller. The customers can freely choose the back-end services: cloud computing and storage on public cloud, private server, or hybrid system. The compute-intensive modules are deployed on a GPU server taking advantage of data parallel with CUDA library. The main features include all standard tools for viewing and diagnosis in 2D and 3D, convenient tools for collaborations, and case management. In addition, advanced functions such as automatic tumor detection and reconstruction and bone/skin/muscle segmentation are provided. This paper describes the details of SkyPACS's design, as well as its implementation and initial deployment. We believe that SkyPACS will soon be available to a broad range of users in Thailand and AEC's countries and will be able to reduce the cost of the healthcare platform in the near future. AU1 AU2

Keywords ∎ , ∎

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8.1 Introduction

In the year 2012, the statistics published by TEH & Associates [1] showed that in every million death, over 120,000 cases are caused by medical error, which was almost four times higher than the death caused by road accidents. Prognosis based on medical imaging is likely to reduce the rate as internal physical anomaly can be visually studied prior to treatments. Medical imagery, such as ultrasound, computerized tomography (CT), and magnetic resonance imaging (MRI), then becomes important tool in diagnosis and is embraced across the global healthcare enterprises.

A hospital around the world nowadays scans a large number of patients each day. For example, a Thailand's university hospital may produce over 1,000 image series from more than 40 patients in a single day [2]. These images have to be diagnosed by the radiologists. However, radiology has not been widely studied in many parts of the world. There are only 4.2 % of medical doctors majoring in radiology in Thailand. The percentage is even much lower in Central and South America where there are less than 1 % in countries like Honduras, El Salvador, Cuba, and Argentina [3]. This insufficiency in human resources may cause the delay in patient treatment. Moreover, the backlog can only get worse as the number of medical cases is growing much faster than the number of radiologists. As a result, it is necessary to facilitate the radiologists so that they can work for multiple healthcare institutes more conveniently with more appropriate number of working hours.

In this chapter, we propose a software solution that can alleviate the mentioned problems. The software is called SkyPACS. SkyPACS is a low-cost and customizable mobile solution for radiologists and medical doctors to view and manipulate DICOM[1] images of any types in both 2D and 3D planes. The solution is an assistive technology with the focus on anytime-anywhere working concept. SkyPACS can also be integrated to any existing Picture Archiving and Communication System or PACS[2] [4].

During the design of SkyPACS, some challenges arise. First, in order to produce a true and natural perception of human anatomy, 3D visualization is needed. 3D visualization in real time, however, is compute intensive and the use of high-performance computing machines is not of low cost. Second, seamless integration to existing systems is difficult since multiple platforms are deployed across hospitals in Thailand. Such integration constrains architecture design choices to client–server with web-based interface. Third, the amount of image data grow so quickly that a cost-effective storage space that can grow on demand may become a necessity. Fourth, different hospitals may have different workflows; creating a one-size-fits-all product is unlikely. Lastly, security is a big issue in patients' data; there is the need for the software to leave zero footprint on mobile devices.

[1] Digital Imaging and Communications in Medicine or DICOM is a universal medical image used in the standard PAC system.

[2] Picture Archiving and Communication System or PACS is a storage and management system for medical image in the standard format, namely, DICOM.

In this work, we have surveyed and selected technologies that are appropriate to overcome these challenges. For the better understanding of the readers, Sect. 8.2 presents an imagery procedure example of radiology departments in Thailand. Then, the software features and design framework are discussed in Sects. 8.3 and 8.4, respectively. Section 8.5 briefly describes the software implementation and deployment. Section 8.6 offers comparisons between our mobile solution and some existing packages. Concluding remarks are then presented in final section.

8.2 Imagery Procedure

In order to allow the solution to be practical, the flow of the imagery procedure from the scanner all the way to the doctors' desktops has been studied extensively with the collaboration of radiology departments in Thailand.

The information flow of the radiology departments is managed by the Radiology Information System or RIS [5]. RIS is responsible for all information involving medical image prognosis, i.e., patient tracking, image case assignments, diagnosis reports, and case transfers. It directly connects to a central system, called Hospital Information System or HIS [6]. Master data, such as patient data, registration, and scheduling, are queried from HIS and stored in RIS using HL7[3] [7] standard. In addition to RIS, radiology process includes another important system called Picture Archiving and Communication System or PACS. PACS can be divided into PACS server and client. PACS client is basically a medical image viewer that communicates with PACS server.

PACS server, on the other hand, serves as the image scan repository for the hospital. On the server, all images are stored in the DICOM format with metadata (image properties, patient and study information, and acquisition information) and image pixels (in bits). Client and server communicate through Query/Retrieve image communication protocol in DICOM standard. PACS client has to select an appropriate image query level which can be arranged in a hierarchical order as follows: patient, study, series, and images. The relationship between levels is one to many; for example, one patient can have multiple studies and one study may contain multiple series. These level definitions are compatible with most PACS.

The workflow of imagery process is shown in 0. Once the patient is scanned through MR/CT scanners, a set of images in DICOM format will be stored in PACS. At the same time, the information of irradiation will be automatically saved in RIS. After the scanning process, the technician will assign the study to a radiologist via RIS management portal. The radiologist will be notified about the assigned study when he/she opens the PACS client. Radiologists can choose the study from the assigned study list for diagnosis. The PACS viewer then fetches DICOM images

[3] Health Level Seven or HL7 is the global standard for exchanging information between medical applications.

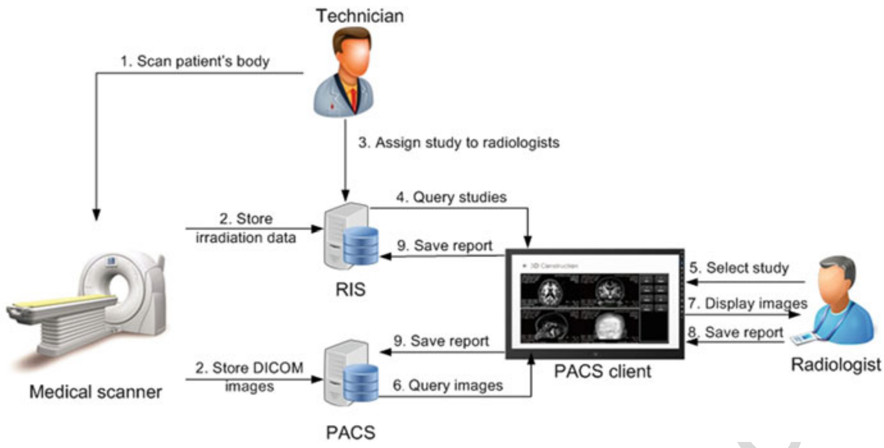

Fig. 8.1 Imagery workflow

from PACS, extracts images and metadata, and displays images with information on the display device. A set of images from different studies or series of the same patient can be fetched simultaneously for display. After the prognosis is completed, the diagnosis report is written and kept in both RIS and PACS. Every radiologist and medical doctor who has the authority to diagnose or medicate the same study can view the existing prognosis report. Furthermore, the image studies are often transferred among radiologists for second opinions (Fig. 8.1). AU3

SkyPACS is designed based on the mentioned workflow. The mobile solution is introduced as an alternative to the current desktop-based PACS client used at most hospitals in Thailand. The following sections described SkyPACS features and its design.

8.3 Features of SkyPACS

SkyPACS can be viewed as a mobile extension to the PACS. The software is service oriented and can work with any PACS server. The main advantage of the software is that the users have the flexibility to choose back-end services: cloud computing and storage on public cloud, private server, or hybrid system. A full Software-as-a-Service or SaaS option is also possible. On the front-end side, devices on any type including iPad, Android tab, Windows 8 tablet, and desktop machines can access SkyPACS through the Internet. Main features of SkyPACS include:

- Dashboard: The case management module which provides the patient information in relations to PACS and RIS. The list of image studies is provided for a specific user based on RIS access right setting. The module can notify doctors when new cases enter the workflow. The doctor can produce text-based reports and email them through the provided UI. Moreover, the module also facilitates doctors in referring cases when a second opinion is needed.

- 2D Viewer: This module is designed to display medical images retrieved from the scanners. Several diagnostic tools are provided including distance measurement, area calculation, standard image enhancement, album viewers, comment authoring, zoom, slice selection, and screen splitting. The screen splitting can be used for comparing images from different studies or series of the same patient.
- 3D Viewer: In this viewer, screens are split into four parts to display anatomy images in axial (top to bottom), coronal (front to back), and sagittal (left to right) planes. Coronal and sagittal images are automatically generated by using the MPR[4] technique when the viewer is loaded and the bottom right window displays the corresponding 3D object. The module interface also allows users to segment the anatomy into muscle, skin, and bone before 3D reconstruction for better visualization. Moreover, the 3D model can be printed directly from the application.
- SkyLink: This is a simple collaboration tool for the users in near proximity to share cases. Cases can be passed along with a simple swipe on the tablet screen, if the receiver has access right to the case file.
- SkySync: This is another tool for collaborative diagnosis. Once the tablets are synced, the users will see the same screen and can work on the images together in a similar fashion as the Google Doc service.
- Brain Tumor Detection: With this feature, SkyPACS can automatically investigate image slices in 2D and make suggestions on where the tumors might be located. Techniques used are a combination of image processing and a rule-based system. Rules given by doctors and templates of organs are used as parts of the decision-making process. The inference engine does reason from the knowledge base like a human would. Once suggestions are made, the doctors can confirm the tumor location and the tumor can then be reconstructed and shown in 3D with the calculated volume.

Sample of screenshots from SkyPACS' features listed above are given in Appendix A.

8.4 Software Design

Our design emphasizes the flexibility as SkyPACS must integrate with multiple PACS servers that run on different operating systems and platforms. The Model-View-Controller (MVC) [8] software architecture is adopted in order to separate the

[4] Multiplanar Reconstruction or MPR constructs the volume by stacking images that retrieved from medical scanner, which is axial slices, together and cuts the volume orthogonally in a different plane to obtain the coronal and sagittal slices.

data and logic from the user interface. The change in one must not affect the others. "Model" represents the medical image data/patient information in the repository. A layer of model services (SkyPACS's main business logic) is provided including functions, such as information retrieval and storing, image extraction, image manipulations, and 3D reconstructions. These services update states of the model. "View" is the output representation in the form of image strings, information in text form, and HTML rendering code. Basically, "View" shows the model states to the user through the interfaces. "Controller" sends commands to "View" to change the presentation and also update the model states according to users' commands. In other words, "Controller" receives user commands from the interface and initiates responses by interacting with "Model," changing its state, and presents the new "View" to the users. Model services are a collection of programs, while the controller services are implemented in the form of web services. In our design, the three components are encapsulated in different layers. Adopting MVC in this service-oriented manner allows SkyPACS to utilize private server with GPU and public cloud storage at the same time. Front-end and back-end services can be selected according to the legacy system already in place at each hospital. AU4

In addition, SkyPACS utilizes the thin client approach, meaning that almost the entire model, view, and controller logics are placed on the server side. The client sends HTTP requests to the controller and then receives an updated webpage in return. Figure 8.2 shows the service layers of SkyPACS along with the service invocation steps. Notice that some controller services are executed on the client through HTML5 technology (along with JavaScript and CSS). These services are related directly to users' commands given through the UI and are left on the client to

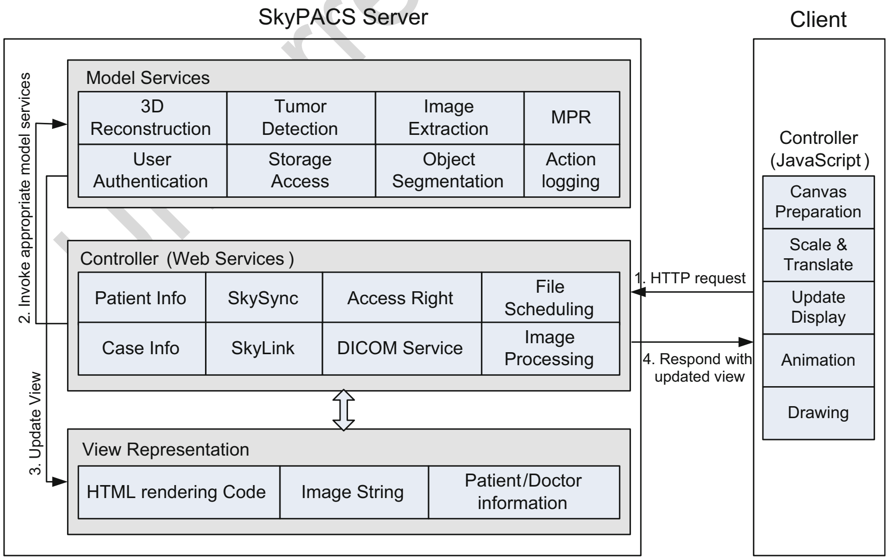

Fig 8.2 Software architecture

reduce communications between the client and server. With HTML5, SkyPACS can be executed on the standard web browser with no plug-in component required.

With the software architecture shown in the figure above, SkyPACS leaves a zero footprint on the mobile devices. Everything goes through the server, which is located behind the hospital's firewall. The client device only caches images when SkyPACS is in operation. Once the software is closed or left inactive for a period of time, everything will be wiped clean. If a doctor loses his tablet, patient information cannot be released. The following subsections describe the design of the two key modules in SkyPACS services, which are 3D reconstruction and PACS storage management. AU5

(a) 3D Reconstruction with GPU Computing

There are two methods typically used in reconstructing objects, which are direct and indirect volume rendering. Using indirect technique, such as Marching Cube [9], an actual 3D model will be created, but the computation is so expensive that an interactive, real-time display becomes a challenge. In order to reduce the time, direct volume rendering, i.e., Ray Casting [10], Shear Warp [11], and Splatting [12], can be used. These techniques create an illusion of a 3D object from a series of 2D images for visualization purpose only. No model is generated. However, with these direct techniques, the processing time required on a typical quad-core server is still in the order of several minutes, which is not sufficiently fast for a near real-time experience. To overcome such a problem, SkyPACS provides data-parallel Ray Casting that can be executed on the graphic processing unit (GPU). NVIDIA's GPU is an inexpensive platform that is highly parallel and is built based on the "many-core" technology. By exploiting the relatively inexpensive GTX780 GPU card and CUDA library, SkyPACS is able to deliver the 3D perception of a large image set in under 5 s. The GPU computing module in SkyPACS can be illustrated in Fig. 8.3.

From the figure, notice that the GPU is installed on the server side and the reconstruction service can be called by a web-based client application through our designed application interfaces (APIs). The host (CPUs) is responsible for DICOM file fetching and extraction. Once the DICOM file is fetched, it is extracted into a set of 8-bit grayscale image files. The header information including image dimension, thickness of 2D slices, pixel spacing[5], slice order, and patient's orientation[6] is extracted into SkyPACS's database. Slice order and patient's information are then used to register images by sequentially stacking the slices. Distances between slices are determined using the

[5] Pixel spacing is an attribute which indicates the physical distance between two pixels. It consists of two values, row and column spacing in millimeter.

[6] Patient's orientation specifies the position of the patient. When facing the front of the imaging equipment, Head First is defined as the patient's head being positioned toward the front of the imaging equipment, while Feet First is defined as the patient's feet being positioned toward the front of the imaging equipment.

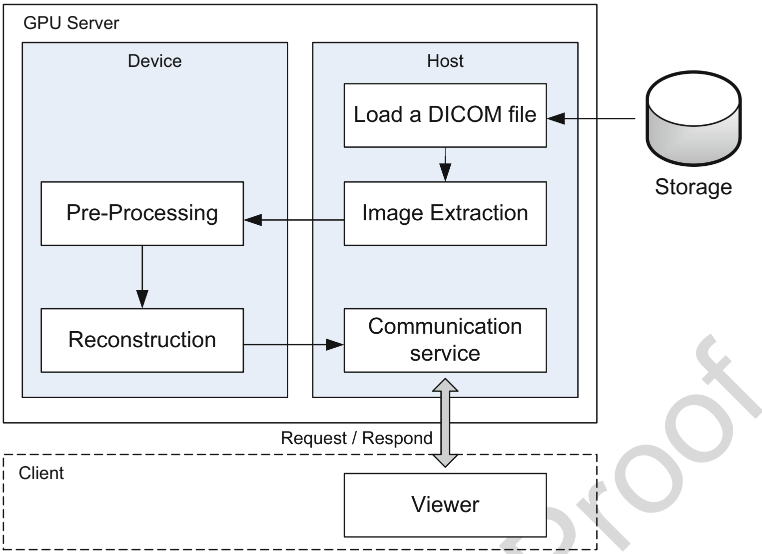

Fig 8.3 3D Reconstruction workflow

extracted thickness and pixel spacing of each slice. The image slices are then sent to the device (GPUs) on the same server. The device is responsible for preprocessing and reconstruction using Ray Casting. The preprocessing step includes normalization and level-contrast adjustment. Depending on users' actions, template matching, and more advanced AI-based algorithms may also be executed for bone/muscle/skin segmentation and brain tumor detection. Once images of the 3D perception are generated, they are sent back to the host, which in turn forward these images to the viewer module on the client device. With this workflow, all the heavy computations are off-loaded from the client device, allowing inexpensive tablets to smoothly run our software as long as there is a good broadband connection. In addition, an actual 3D model will never be generated unless a user chooses to print an object with a 3D printer. AU6

(b) PACS Storage Abstraction

Medical image files are large and patient's data are needed to be kept for at least 5 years after a case becomes inactive. The file storage that serves PACS then needed to be extended frequently causing tremendous overhead to the hospitals. On average, a hospital in Thailand adds around 8 terabytes of storage per year. To remedy the problem, SkyPACS adopts storage abstraction concept where repository layer is abstracted from the software and files can be transferred back and forth automatically between local storage and the cloud. The local storage can be any legacy storage of a hospital, and the cloud can be any public cloud, such as Microsoft Azure or Amazon EC2. These cloud storages can flexibly be extended or shrunk on demand.

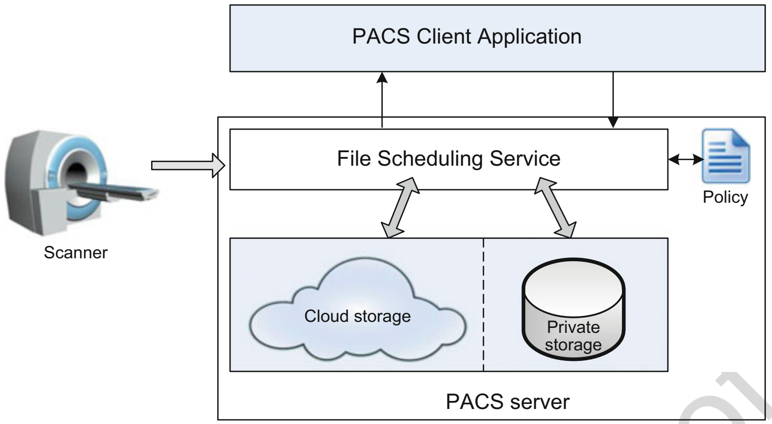

Fig 8.4 A file scheduler

SkyPACS implements a file scheduler as a service to be called by any PACS client application or viewer. Figure 8.4 illustrates the scheduling service. When a scanner or a client system needs to write image files, a file scheduling service will automatically select appropriate disks to store data according to the policy defined by a system administrator through a provided GUI.

One example policy is for an administrator to set a threshold value that specifies when image files should be transferred from a local repository to the cloud. The file selection is performed based on the Least Recently Used or LRU algorithm. In other words, the least recently accessed files will be transferred first, while the most recently accessed files will always be stored locally. When the read access is required, a file scheduler will locate, retrieve, and forward automatically the requested files. Thus, PACS server will be able to use the local storage in combination with the cloud without the knowledge of the physical location of each file. The abstraction layer allows the repository management to be flexible. Moreover, the policy can be changed without affecting file-accessing workflow.

8.5 Implementation and Deployment

SkyPACS is implemented as a 3-tier service-oriented application. The interface responsible for interacting with end users is web based with no installation required on the client side. Touch screen input and gestures are carefully developed for the simplicity and ease of use. We emphasize the use of an open platform with HTML5, JavaScript, and CSS for the front-end modules. These technologies are compatible on most browsers and tablets. The core business logic of SkyPACS is implemented on .NET framework. The web services and service protocol are built based on Windows Communication Foundation or WCF. On the back-end computing,

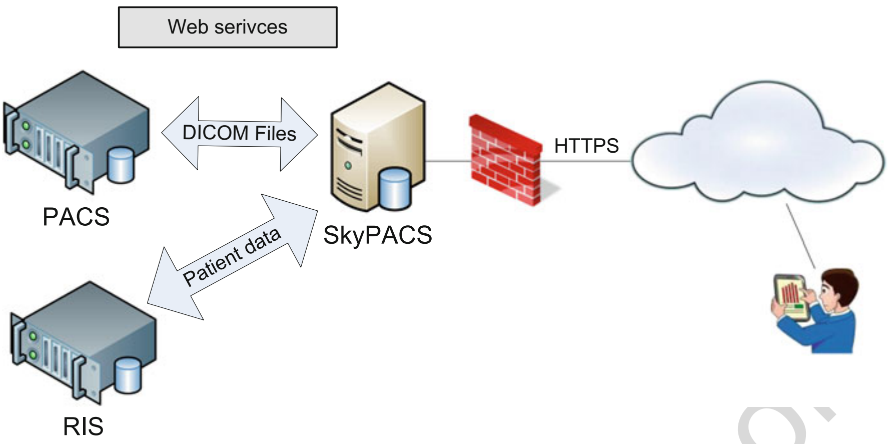

Fig 8.5 Network connection

CUDA-C and C++ are used for 3D reconstruction and other compute-intensive services. SkyPACS server runs Windows operating system with Internet Information Service or IIS web server as this is the standard platform used in Thai hospitals. The SkyPACS storage server is implemented with MySQL and open source DICOM toolkit.

SkyPACS has currently been deployed at one of the MRI centers and is scheduled to be deployed at another university hospital in Thailand in the last quarter of 2013. With data security as the main concern, the implementation is done in such a way that all patient data and case files are streamed through the encrypted channels on demand. We deployed a SkyPACS server at the customer site and open a series of connection channels between SkyPACS and PACS server. The number of channels created depends on the number of concurrent users specified by the customer. When an end user requests data, SkyPACS queries RIS for patients' information and PACS for DICOM files. The information is then stored in SkyPACS data server, which sits behind a firewall. A dedicated communication channel between PACS and SkyPACS server is then assigned to each user session. Requests/responses are then carried out using the channel until the user terminates the application. If the session time is over, the communication channel will also be reassigned. Figure 8.5 illustrates the network connection.

8.6 Product Comparisons

This section compares SkyPACS with some commercial medical imaging software packages available in Thailand, namely, RadiAnt [13], Synapse Mobility [14], and OsiriX HD [15]. Similar to SkyPACS, these mobile solutions were designed to be a viewer of DICOM files and offer standard tools such as zooming, panning, marking, and image manipulation tools.

RadiAnt is a Windows-based solution designed to be a stand-alone viewer. Connection to any PAC systems will be a challenge. The software requires the user to manually provide the data through CD/DVD media. Image data are stored in the device's storage. Without a predefined method to pull data from PACS, RadiAnt cannot be seamlessly integrated to the hospital IT platforms.

Synapse Mobility is a web-based solution developed to be an extension of *Synapse product suite* which is a clinical workstation solution. Once the data are requested through Hypertext Transfer Protocol or HTTP, they will be sent over the Internet and cached in the device in a similar fashion as any web application does. Synapse Mobility requires that a hospital uses Synapse product suite, which is one of the solutions with a very high cost.

OsiriX HD is an iOS application developed to be both stand-alone and extension solutions. User can either manually provide the data or connect the application to any standard PAC system. Once data are presented, they will be stored in the device's storage. Moreover, OsiriX HD is restricted to iOS platform.

In our study, we compare the products in four dimensions: data security, supporting platform, PACS compatibility, and cloud integration. Details are below.

The handheld device presents more risk of data being stolen than the desktop machine located in the hospital. This is an important issue since the sensitivity of medical data and patient's record is very high. Leaving a zero footprint with no plug-ins or image data on the client device is necessary in many usage scenarios. From the four packages, only Synapse Mobility and SkyPACS were implemented based on this concept.

As there are several popular platforms for mobile devices nowadays, portability across platform is important. RadiAnt and OsiriX HD are restricted to a specific platform making them less flexible. Synapse Mobility and SkyPACS then have an advantage.

Most radiology departments have already installed a PAC system; the integration with the existing PACS is expected for a mobile extension. All packages but RadiAnt offer an option to connect to PACS through the standard DICOM protocol. Among the 3 packages, Synapse Mobility restricts the integration to Synapse PACS only. Unless the hospital deploys the Synapse workstation, this mobile extension is not available.

In order to effectively manage PACS storage and 3D image computation, cloud integration has been studied. From the survey, RadiAnt and OsiriX HD are native applications and are required to operate on the device's processor; cloud integration is unlikely. Synapse Mobility also requires the specific PACS and cloud option is not currently available. SkyPACS is differentiated from the others due to the fact that SkyPACS's back-end services can be customized and integrated to any server platform.

To summarize, SkyPACS was designed by compiling benefits from the product survey and extending some features to maximize the capability of the application.

Conclusion

SkyPACS is a mobile solution that is designed to be fully service oriented. Front-end and back-end services are encapsulated and thus independent of one another. The software emphasizes the ease of use as well as the ease of integration. The main advantage of SkyPACS is that it can be integrated with any PAC system at any healthcare institute. Product customization is possible at a low cost. Virtualization on the cloud and computing on the GPU are also fully utilized in the design. In summary, SkyPACS has been developed based on the cutting-edge technology in the field of mobile and cloud computing. The road map of the development efforts will include the performance improvement in the 3D domain. More advanced features will also be developed including blood vessel reconstruction, computation staining, as well as automatic mobile offloading. With our on-going research works, we believe that we will be able to continuously fine-tune and improve the user experiences in the future.

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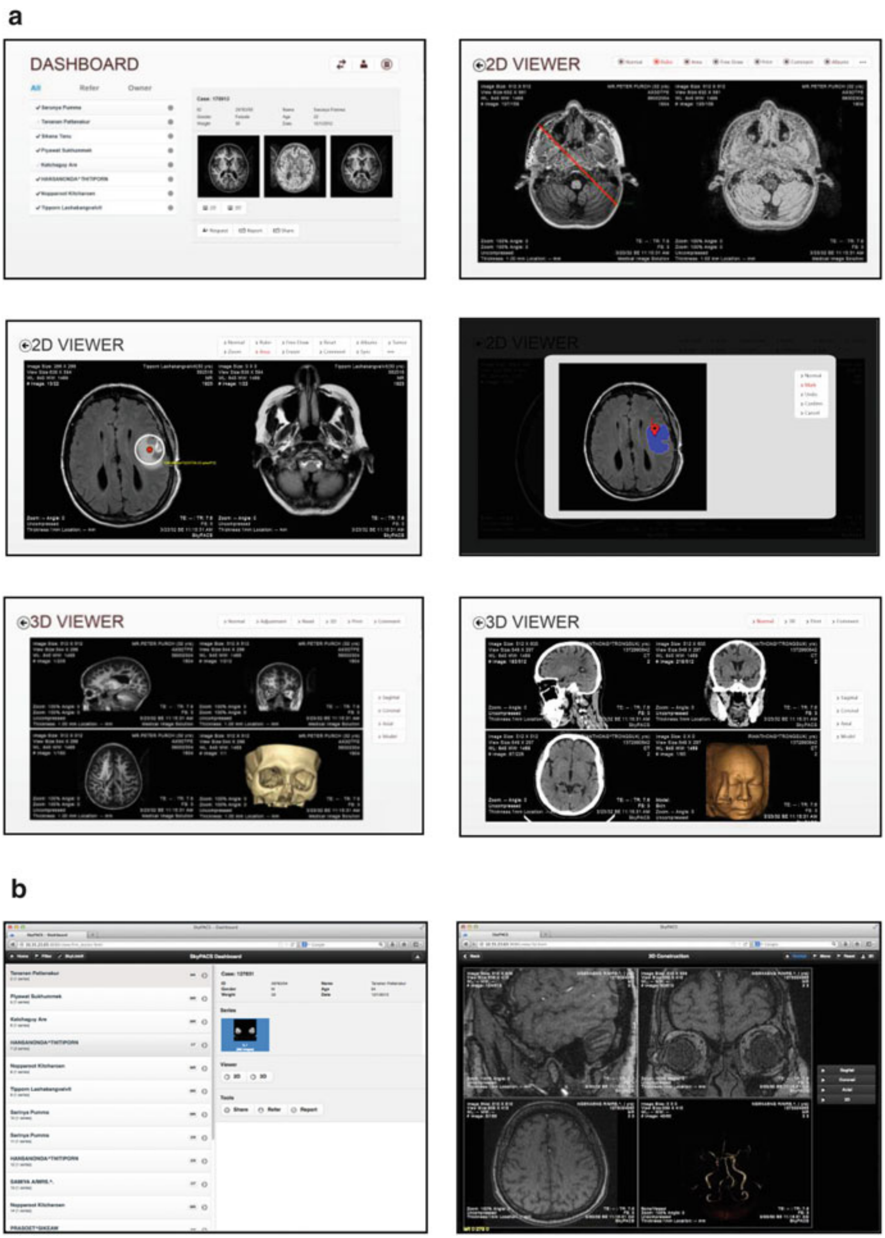
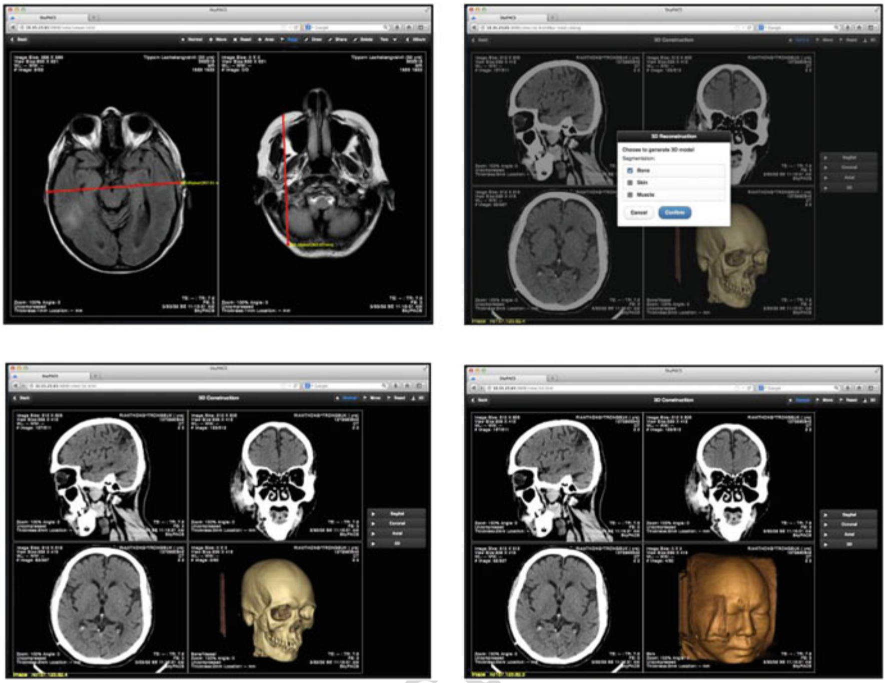
Appendix A: Screenshots

(a) Windows 8 Version



(b) Web-Based Version



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Author Queries

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Query Refs.	Details Required	Author's response
AU1	There is an inconsistent usage with regard to capitalization of several terms, such as model, view, and controller. As these are context specific, we have retained the usage as in the MS. Please check if this is okay.	
AU2	Please check and provide keywords.	
AU3	Please check the suggested intext citation for Fig. 8.1.	
AU4	Please check sentence starting "Multiplanar Reconstruction or MPR..." for sense.	
AU5	Please check if generic usage of "his" should be changed to "his or her" for gender neutrality.	
AU6	Please check sentence starting "Depending on users'..." for completeness.	