The Use of Mobile Phones in Radiology

Ivan Drnasin [1], Mislav Grgic [2]
[1] Infomedica, Split, Croatia
[2] University of Zagreb, Faculty of EE and Comp, Zagreb, Croatia
drnasin@hotmail.com

Abstract **- This paper will explore current state of the art in bringing radiological images to modern mobile phones. Short history is given, with focus on PDA devices, and current software development process is described with focus on smartphone mobile web browsers.**

Keywords **- radiology; DICOM; smartphone; PACS; mobile web browser**

I. Introduction

Radiology is the branch or specialty of medicine that utilizes imaging technologies to treat disease. Digitalization of radiology is process of replacing analog image (on film medium) by digital one (on electronic medium). It is achieved by digitalization of analog image devices, usage of modern digital image devices and implementation of RIS (Radiology Information System) and PACS (Picture Archiving and Communication System) in radiology department. PACS is used to store, transfer and process digital images.

Digital radiology image is two-dimensional array of positive integers $f(x, y)$, where $1 \le x \le M$ and $1 \le y \le N$, M and N represent number of image rows and columns (image width and height). Standard for storing and transferring digital radiological images is DICOM (Digital Imaging and Communication in Medicine). Digital radiology images are usually called DICOM images. They are stored with 10, 12 or 16 bit per pixel, generating up to 65.000 grayscale values.

Since modern computers work with 24 bit color hardware (graphic card and display) which can represent 256 grayscale values (8 bit), transformation of 16 bit DICOM images to 8 bit graphic system is needed. Usually, this is not a one to one transformation; image values less than a certain threshold are clipped to black, and image values greater than a certain threshold are clipped to white. Two parameters are usually chosen that determine the slope and end points of this transformation function: the window and level (W/L) [1]. Transformation can be dynamical, when whole DICOM image is stored in local memory and transformation is done on local computer, or non-dynamical, when on client request server transforms image and returns DICOM image snapshot with specified W/L parameters [2].

Medical community (especially the radiology community) is considered to be both an adopter and innovator in the use of the PDA (Personal Digital Assistant) and the smartphone devices in the workplace [3]. The practice of medicine is based on accumulating clinical patient data, applying data analysis and medical references to diagnose, and defining appropriate therapy.

With availability of PDA devices and mobile phones to whole world population, some authors have proposed and developed radiological software for PDA and mobile phones.

II. PDA and Mobile Phone Studies

Studies and research that have been carried out about PDA devices and mobile phones in radiology can be divided in functional and clinical.

A. Functional studies

Functional studies have been conveyed mostly on PDA devices. Early studies (2001-2003) are focused on platform adoption and software development. PDA devices were limited with 2-64 shades of gray; from 160x160 to 240x320 pixels screen resolution; 8-64 MB of RAM with limited storage space (16-64 MB Flash ROM); 60-200 MHz of processing speed; Wi-Fi and rarely GPRS network access. Researchers could choose between Windows Pocket PC, Palm OS and Linux OS [3]. Developed software was able to manipulate radiological images in simple but adequate form: change window width and level with zooming and panning. Main problem for adopting such solutions was downloading speed and display quality [4].

When manufacturers started to add GSM capabilities to the PDA devices, with faster processors and more memory, they called them smartphones. Several studies from 2004 to 2007 showed that PDA devices, in combination with wireless networking, image processing and analysis, can be used for medical teleconsultation in a wireless covered hospital environment [5]. Problem was in lack of the PDA software designed for radiology available on the market [6]. Few studies at that time have proposed idea of accessing images from mobile web browsers by using HTTP protocol [7, 8].

One of the interesting points in the development of mobile radiological application was release of Osirix iPhone by Osirix Foundation in middle of 2008 [9]. At that point handheld radiology started to fulfill expectations, because it was available to everyone, not only to small research groups in terms of non-market software. One of the big achievements of Osirix mobile application was implementation of DICOM networking protocol and UI (User Interface), which enabled usage of application in intuitive way with every PACS server.

B. Clinical studies

Clinical studies have been concentrated on image analysis and reporting.

On RSNA (Radiological Society of North America) 2007 meeting research group from Dublin, compared a Dell Axim X50v PDA and a Dome C3i display for diagnosing acute cranial bleeds. They concluded that PDA is accurate as the reporting workstation. But, the radiologists will have to adapt their reporting technique when using the PDA to avoid generation of excessive false positive diagnoses [10].

Another group presented, at RSNA 2008, evaluation of the accuracy of appendicular trauma X-ray interpretation in smartphones compared with PACS workstations. Results showed that accuracy of interpretation of appendicular trauma radiographs on the Apple iPhone is high from 93% to 98%. Conclusion was that smartphones (such as the Apple iPhone) have a future role in providing second opinions in appendicular trauma. They also consider that improvements in software and hardware technology are needed. [11].

Research group on RSNA 2009 concluded that 15 of the 25 patients were correctly identified as having acute appendicitis on 74 (99 percent) of 75 interpretations, with one false negative, using Apple iPhone device with Osirix iPhone application. Clinical relevance, authors consider, may be in remote viewing of studies for emergent consultation [12].

The researchers from Dublin wanted to determine if the diagnostic accuracy of handheld devices was comparable to the monitors that may be used in emergency teleconsultation. They compared Dell Axim and Apple iPod Touch PDA with Viewsonic VG810B LCD monitor (resolution of 1024 x 1280 pixels on 18 inch). Each device was tested against the secondary monitors with both posteroanterior wrist radiographs and brain CT slices. The study team found that there were no statistically significant differences in overall reader accuracy for either wrist radiographs or brain CT images regardless of whether they were viewed on the iPod Touch or the secondary monitor, although some comparisons approached significance [13].

Research team at the American College of Cardiology (ACC) annual meeting in Atlanta presented that the mobile application (MIMvista) yielded 100% sensitivity, 78% specificity, and 100% negative predictive value in predicting stenosis, comparable to previous multicenter studies employing 3D workstation software. The group also found that heart rate and heart rate variability were the factors most likely to affect diagnostic performance of the technique [14].

Results of all studies show that specific PDA and smartphones can be used for evaluation of digital radiological images, at least, in emergency events or for preliminary diagnosis [22].

C. Smartphone as medical device?

EU (European Union) defines a medical device as any instrument, apparatus, appliance, software, material or other article intended by the manufacturer to be used for human beings [15].

A medical device, according to the US Food and Drug Administration (FDA), is an instrument, apparatus, implement, machine, contrivance, implant, in vitro reagent, or other similar or related article intended for use in the diagnosis of disease or other conditions. Medical devices are regulated by the FDA Center for Devices and Radiological Health (CDRH) [16].

1) FDA prohibits usage of smartphone for diagnostic in radiology

In January 2010, CDRH informed software developer MimVista from Cleveland that its Mobile MIM image viewing and multimodality fusion software for the Apple iPhone device was not substantially equivalent to predicate devices, based on MimVista proposed indication for displaying medical images for diagnostic use on a mobile device. FDA also said that the device also has new technological characteristics that raise new types of safety and effectiveness questions [17].

2) EU allows smartphone diagnostics in radiology

The same Mobile MIM image viewing software by MimVista company has received the European CE Mark. It is currently available in the UK (United Kingdom), Australia, Hong Kong, Singapore, and India [17].

III. ELABORATION

To show DICOM image on smartphone one must think of 4 things: image display, transfer, storage and software. We will follow ACR (American College of Radiology) standard for practicing teleradiology, to show all relevant points in our elaboration.

A. Image display

According to ACR, for small matrix size images (computed tomography (CT), magnetic resonance (MR), ultrasound (US), nuclear medicine (NM), digital fluorography (DF), and digital angiography (DA)), the data set should provide a minimum of 512 x 512 matrix size at a minimum 8-bit pixel depth (256 gray levels) for processing or manipulation with no loss of matrix size or bit depth at display [18].

Modern smartphones have surpassed classical 240x320 resolutions. Smartphones screen height goes up to 854 pixels; width goes up to 480 pixels. They still lack 32 pixels to achieve 512 pixel widths. Image has to be resized to fit screen, or in full size with panning support. Display sizes vary from 3 to 4 inch, where larger display size is better. Color depth can be 16 bit, 18 bit or 24 bit, providing 40 to 256 gray levels. For practicing radiology many other display parameters of smartphone are relevant: color quality, absence of artifacts, peak brightness and black level brightness [19].

B. Image transfer and networking

By including IP protocol in mobile networks, mobile phones are capable of accessing Internet by mobile web browsers, email and other network services. Image transfer from PACS archive to mobile phone can be achieved by TCP/IP-based network protocols: DICOM, HTTP, FTP, SMTP or proprietary network protocol.

There are already mobile applications that implement DICOM network protocol [9, 20] and take full advantage of retrieving DICOM images from every PACS. Development of

DICOM protocol is complex process [21] and developers might consider using HTTP protocol. Benefit is that mobile web browser can be used to read DICOM images from PACS archive with WADO - web-based method of retrieving DICOM images from PACS archive by using HTTP/HTTPS protocol [2]. By using WADO method, PACS sends, on web browser HTTP request, DICOM image snapshot with specific W/L preset in web browser readable formats (JPEG/PNG/TIFF/GIF/BMP).

Transferring or downloading speed varies by type of wireless network, which can be: short range Bluetooth (2 Mbps) and Wi-Fi (54 Mbps); long range HSDPA (14 Mbps), EDGE (400 kbps) and GPRS (114 kbps). Table 1 shows image transfer speed for MR and CT image series, retrieved through WADO method on HTC TyTN mobile phone, as a series of JPEG lossless images with quality level Q = 75 [22].

TABLE I. IMAGE TRANSFER SPEED [22]

	20 MR images	56 CT images
Wi-Fi	19 s	26 s
UMTS/HDSPA	25 s	32 s
EDGE	26 s	41 s

C. Storage

DICOM images vary in size. Table 2 shows common values for DICOM images [23]. Storing data on mobile devices is no longer a problem, since most devices have external storage on removable flash memory card, which can store up to 32 GB. Keeping that in mind, one memory card can hold several hundred CT studies on a mobile phone.

TABLE II. SIZE OF COMMON MEDICAL IMAGES [23]

	One image (size/bits)	Images per exam	One exam size (MB)
Nuclear medicine (NM)	128 x 128 x 12	30 - 60	1 – 2
Magnetic resonance (MR)	256 x 256 x 12	50 - 2000	8 - up
Ultrasound (US)	512 x 512 x 24	10 – 240	5 - 60
Digital subtraction angiography (DS)	512 x 512 x 8	15 - 40	4 - 10
Computed tomography (CT)	512 x 512 x 12	40 - 3000	20 – up
Computed digital radiography (CR/DR)	2048 x 2048 x 12	2	16
Digitized X-ray	2048 x 2048 x 12	2	16
Digital mammography (MG)	3000 x 4000 x 16	4	160

D. Software development

According to ACR standard, teleradiology system must be capable, among other features, for: selecting image sequence; accurately associate the patient and study; adjust window and level if those data are available; pan and zoom image; rotate or flip the images provided; correct labeling of patient orientation is preserved; calculate and display accurate linear measurements and pixel value determinations in appropriate values for the modality (e.g., Hounsfield units for CT images), if those data are available; display prior image compression ratio, processing or cropping [18].

We will explore two methods of application development: mobile operating system based (OS) and mobile web browser based.

1) *Mobile OS based development*. It is not the same if one develops mobile application for European, Asian or North American market (Figure 1.). Main question is which devices radiologists use, or are about to use? That question we will leave unanswered since new devices are coming on daily basis and every new device brings new features better then competitors.

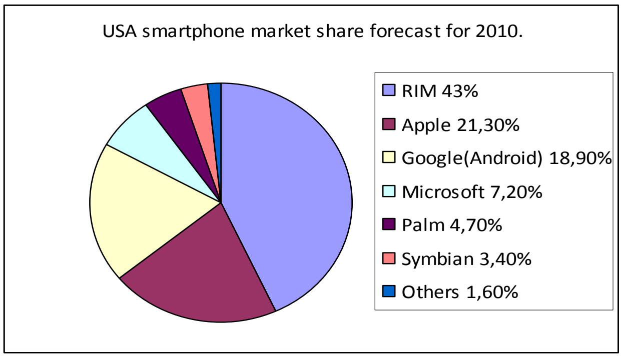

Figure 1. Smartphone market share in USA, forecast for 2010 [24]

Development should be based towards devices with best characteristics for DICOM image viewing, or for platform that provides best devices, or for platform that provides best developing tools. Probably, main objective is to develop software that reads DICOM files, where main programming challenges are different image compression techniques (RLE, JPEG, JPEG2000) in reversible and irreversible form. If one develops in C or Java language, open source DICOM toolkits are available which speed development process (e.g. DICOM Offis toolkit and PixelMed Java DICOM Toolkit).

2) *Mobile web-browser development*. On the other side, web-based applications are gaining popularity since mobile web browsers are capable of executing complex and dynamic tasks. Web-based application development is good way of bringing radiological images to mobile phones. Mobile web browsers are preferred for executing mobile radiological applications because:

- application is available to all mobile OS;
- mobile web browsers support ECMAScript for developing client based image processing;
- support for XMLHttpRequest object for asynchronous image retrieval;
- support for Cascading Style Sheets (CSS) standard for changing image size, panning and UI development;
- support for SVG (Scalable Vector Graphics) for vector based drawing on images (annotations, measurements etc.);

- support for main parts of HTML5 standard for web browser based image storage, dynamic image manipulation, applying various filters etc.;
- mobile web browsers can handle large data sets, as loading big web pages, show streaming video (in Flash) [25];
- there are several hi-performance mobile web-based browsers [25] that have been tested with such applications and proved to be efficient [22];

Main question is how images are going to be retrieved from PACS? Since web browsers do not support DICOM protocol, images should be transformed to supported formats (JPEG/PNG/TIFF). WADO method can be used to retrieve images in those formats. JPEG is probably most suitable format:

- supported by DICOM standard in reversible and irreversible compression modes;
- JPEG quality levels can be optimized according to network speed.

By using WADO, DICOM images are actually JPEG snapshots with defined W/L. It is important to note that every W/L change results in HTTP request to WADO server. One such example is Oviyam project [26], where user first selects W/L parameters and then ask server for image. Another approach can be to request constantly highly degraded JPEG images ($Q < 20$) and simulate interactive W/L as in OS application.

Drawback of described radiology web-based applications is demand for WADO support at PACS server and lack of interactivity when performing W/L. Big improvement can be made by using HTML5 standard and transferring W/L processing on client side.

IV. Discussion

Smartphone available today can have characteristics as presented in Table 3. It is important to notice arrival of Super AMOLED (Active Matrix Organic Light-Emitting Diode) display with integrated touch functionality without glass layer, producing better and natural color display [27]. Such displays might improve usability in medicine, especially radiology.

After first PDA stage of mobile radiology, second smartphones stage with limited software is here for some years, and now third stage can begin – software stage. Smartphone devices are powerful as desktop computers several years ago. Only software development remains unsolved. Beside two mobile radiology applications available on Apple iPhone platform, other platforms lack of any mobile imaging application (there are some exceptions [28]). It is similar situation in 3D medical imaging on handheld devices: 2 manufacturers have announced thin client (image is reconstructed at server and streamed to client) solutions on Apple iPhone platform [29, 30].

TABLE III. Characteristics of modern smartphone

Attribute	**Value**
Display res.	480x800 pixels
Display size	4.0 inch
Display color	24 bit color, 256 grayscale levels
Display type	Super AMOLED or LCD
Processor	1 GHz
Memory	256 RAM, 32 GB storage
Short range net.	Wi-Fi 54 Mbps
Long range net.	HSDPA 7.2 Mbps
Web browser	WebKit-based

Above mentioned platform is dominant today in mobile radiology applications. Since many new devices are available, with more advanced characteristics, other platforms should be considered too [31]. In the meantime, web-based radiology applications fill the gap. They may lack in interactivity but win in availability.

V. Conclusion

Advanced characteristics of today smartphone devices challenge application developers to develop new radiological applications. Mobile web-based radiological applications can satisfy (with image display, images retrieval and toolset) basic and advanced requirements of radiologists in everyday medical image analysis.

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