JPEG2000 Features for Ubiquitous Healthcare Device Interface

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ABSTRACT

The paper describes features of JEPG2000 still image compression that are usable in ubiquitous computing environments for medical work (ubiquitous healthcare environment). These features facilitate the interfaces (human and storage/transmission) of devices used, especially for handheld devices. The ubiquitous healthcare relies on extensive use of handheld devices with all their limitations. Beside conventional textual and low-memory data, the goal of ubiquitous healthcare is to achieve transmission of digital medical images. Although the power of handheld devices have increased over the years it is still necessary to use some restrictions on medical images such as image compression and streaming. The goal is not to devise a system for transmission of medical images to handheld devices only, but to implement a ubiquitous healthcare environment which will transmit medical data from the same source with the same efficiency to different devices with different processing and display capabilities. Simple and adaptive human interfaces combined with JPEG2000 influence the adoption of handheld devices into a ubiquitous environment. They also influence the perceived quality of received medical images. The paper advocates the JPEG2000 still image compression as one of the ideal tools for achieving medical image transmission and display throughout ubiquitous healthcare.

Keywords: JPEG2000, ubiquitous computing, Picture Archiving and Communication System, human interface, user interface, medical image display, medical image transmission

1. Introduction

Although the computers are used in hospital environments, they are mostly restricted to certain areas such as physician's office and medical rooms with specialized equipment [1, 2, 3]. The modern day hospitals become highly interactive environments. Medical staff becomes extremely mobile. Their environment and context of work is ever changing [2, 4]. Therefore the benefits that computers brought to healthcare are not available most of the time [1]. Digital medical data are useful for medical staff during many situations such as patient bad-side visits, emergency situations, out door consultations, etc. Conventional computing based on desktop computers is not a solution for these situations. The ubiquitous healthcare is computing paradigm in which computers are integrated in a seamless way in everyday medical practice and clinical work. This means that computers are everywhere, at disposal to medical staff at any time. Beside conventional places, in ubiquitous healthcare computers are on hall walls, on cantina tables, near patient bad-sides, in physicians' hands, and in physicians pockets [5]. Medical data flow is automated, context-aware and instant.

Handheld devices (PDA, mobile phones) play an import role in achieving the ubiquitous healthcare. They are light and wearable. Most of them have the ability to connect on broadband mobile networks which makes them accessible almost everywhere. Also, they are quite common and widespread [6, 7]. Handheld devices are useful in many scenarios for ubiquitous healthcare because they can be carried in pocket. They can be manipulated with one hand while the other hand is available for other operations. Well designed human interface enables the physician to watch data displayed on handheld device (for example a X-ray medical image) whilst checking the injured spot with his other hand. The data displayed on handheld device is changing as the physician moves from patient to patient.

Although their power has been increased over the years, handheld devices have limited processing power, small storage capacity and small size displays (approximately 3.5 inches diagonally). Although they cover large areas, mobile networks are still low-band networks [3]. The handheld devices cannot be used in efficient way inside existing conventional medical systems which are designed to transmit large amounts of medical data over high-pass networks to conventional desktop computers or dedicated medical devices. Most commonly handheld devices have been used to display textual and binary data.

Important aspect of medical data is digital medical image. It would be most useful for ubiquitous healthcare to facilitate transmission and display of medical images on handheld devices. This would enable full immersion of medical stuff into ubiquitous healthcare environment making them full time part of the environment. Medical images are very big in size. Because of the low resolution, it is possible to display only a low resolution image or only a part of the image on handheld device. Medical images are not convenient for transmission over mobile networks [8, 9]. It takes long time to download the complete medical image. It is possible to keep and handle only limited number of medical images in the memory of a handheld device.

We address the problem and solution in human interfaces for displaying digital medical images on handheld devices. It is not enough to facilitate fast and secure transmission of medical images to handheld devices only. The human interface should support fast image zooming and panning of the medical image. For the most of the commercially available handheld devices, this is not achievable for sets of medical images or for large medical images of original size [8, 10]. The user interface of handheld device should be designed with much care because it influences the perceived quality of the displayed medical image and it can increase/decrease overall usability of the device. Because the screen of handheld device is of limited size, user interface should be simple and flexible.

JPEG2000 still image compression standard has several features very appealing for transmission of medical images to handheld devices [10, 11, 12, 13, 14] such as high compression ratio with minimal distortion within decompressed image, protection against errors on wireless networks, image streaming, and region of interest coding. These features advocate JPEG2000 as a tool for transmission of medical images to handheld devices because they enable fast transmission of medical images in the best possible quality. Image streaming and region of interest coding, enable presentation of medical images in different resolutions and the best possible quality for given resolution. The same technique is used to transmit medical images to conventional devices and to handheld device thus creating truly ubiquitous healthcare environment.

The organization of the paper is as follows: section 2 describes the ubiquitous healthcare environments and devices; section 3 describes JPEG2000 features for ubiquitous healthcare device interface; section 4 describes the user interface design for ubiquitous healthcare; and section 5 concludes the paper.

2. Ubiquitous Healthcare Environments and Devices

The scope of ubiquitous healthcare is not restricted on hospital environment only. It is interlaced with telemedicine (although it is not a rule) [1, 6]. There is a constant need to bring medical data outside the hospital to emergency units, to remote physicians, and to rural hospitals [15, 16, 17, 18]. Also there is need to bring healthcare to patient homes and patient bed-sides. Small sized devices mounted on patients bodies enable the constant, everyday, monitoring of patient health [6].

The field of telemedicine is well established and it is still advancing [6, 19]. There is a high knowledge base, well documented, and there are several working telemedicine systems which form a ubiquitous healthcare environment [5, 13, 15, 20, 21, 22, 23, 24, 25]. We demonstrate ubiquitous healthcare on these environments in order to identify interaction devices, figure 1 and figure 2.

Figure 1 describes patient-centric ubiquitous healthcare environment. A patient’s vital parameters are monitored and transmitted to corresponding healthcare institutions and staff. Patients are equipped with small sensors constantly monitoring their health. These devices are connected to devices with more computational power like mobile phones and PDAs. Data from sensory devices are transmitted through mobile devices to medical

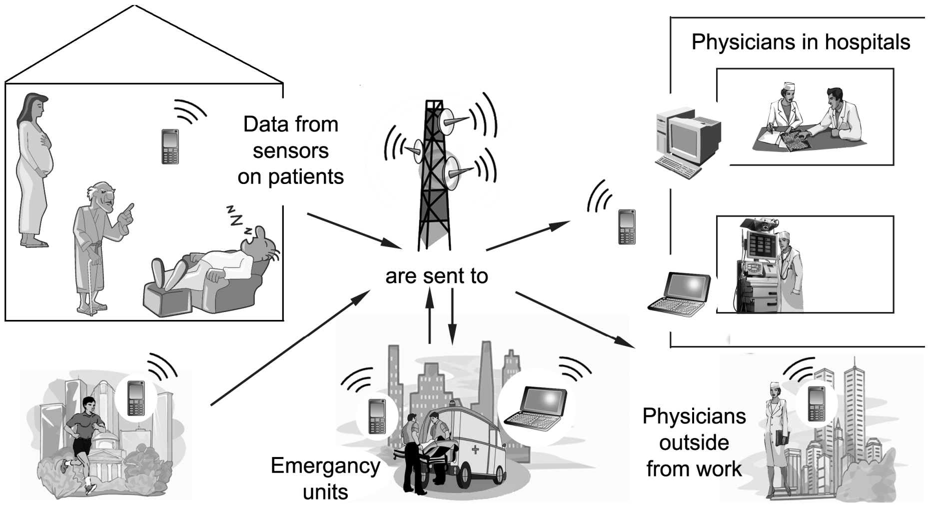

Figure 1. Example of patient-centric (patient monitoring) ubiquitous healthcare environment

networks and there to corresponding medical staff and institutions. Context awareness is brought into the patient monitoring environment through ubiquitous healthcare. If abnormalities are detected, corresponding physician is alerted. He/she can contact the patient and give him proper advice. It is possible to monitor the health of the entire population [19]. It is possible to detect the heart attack on previously healthy person and to react in time. In the case of the emergency, the closest medical institution is alerted and the most appropriate help is available in shortest time.

Figure 2 describes ubiquitous healthcare environment for medical staff. Wherever they are, no matter the time, medical staff remains part of the healthcare environment. Physicians can request consult from other medical specialist, give consult to patients or other physicians, emergency units can request consult or patient electronic medical data. When system is context aware, emergency unit computer devices are automatically updated with patient medical data.

Ubiquitous healthcare incorporates three classes of devices from figure 1 and figure 2:

(i) ***stationary devices*** such as desktop computers, dedicated medical devices, and context aware medical monitors (mounted on walls in hospital halls, or beside patients bad),
(ii) ***movable devices*** such as laptops and personal medical assistants (kind of tablet PCs), figure 3,
(iii) ***handheld devices*** such as PDAs and mobile phones.

In most cases stationary devices (i) are conventional medical devices that can process and display medical images in original resolution and quality. Some of these devices such as context aware medical monitors are exclusive tools of ubiquitous healthcare. The content of these monitors is changing to facilitate the needs of their current user automatically. Monitor near patient's bad

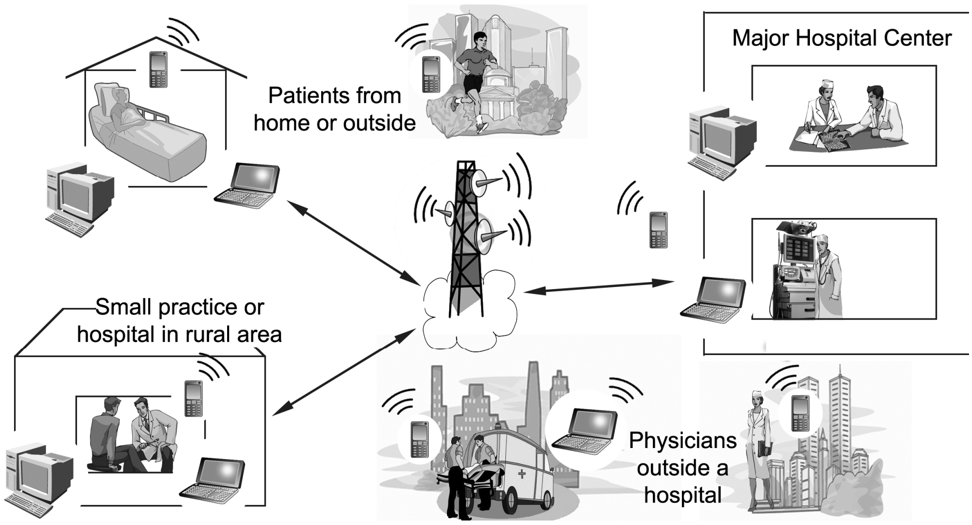

Figure 2. Example of (in and out of a hospital) ubiquitous healthcare environment for medical staff

Figure 3. The Motion C5 Table PC (Taken from: www.healthline.com)

displays ordinary TV program while patient is alone. When physician comes to check the patient, monitor displays patient electronic medical data [1, 3]. Unfortunately, users have to be near by stationary devices to use them, thus spending valuable time.

Movable devices (ii) represent lighter versions of their stationary cousins. Although their processing capability is not far behind conventional PCs, they usually have displays of smaller size. They can process and display medical images in original or smaller than original resolution. Movable devices have limited portability [5, 8, 16]. Some of them, like laptops, have quite some weight. Also, movable devices have limited usability. Because of its size, it is impossible to hold laptop computer in hand and use it. Even personal medical assistant has limited usability. Although it is lighter than laptop and it is designed to be carried around, user needs both his hands to use it.

Handheld devices (iii) have the highest mobility from all three classes of devices used for ubiquitous healthcare. But this also means that they have limited processing capability, memory capacity and small display size. It is very easy to incorporate them into ubiquitous healthcare environment. Because they can be held in pocket they are accessible all the time. Also, when physician approaches the patient, physician handheld is immediately updated with patient's electrical medical record [1, 2, 4]. It is very easy to combine handheld devices with stationary devices. Physician's handheld device and context aware medical monitors can be updated with the data from the same set. The handheld can contain private, sensitive data and low resolution medical images while monitors can display high resolution and high quality medical image of the patient. Handheld devices are very convenient for scheduling tasks in healthcare environments [4]. They enable rightly timed and precise communication. When nurse arrives at patient's bad-side if the time is right, he/she gets the instructions for patient treatment. For example, if he/she arrives at 7 o'clock p.m. and if that is the time for patient medication, he/she will receive the message to give the patient his treatment. In same way physicians could leave messages for the next physician who visits the patient (for example in the next shift).

When mobility is needed (as it is in medical environments [1]), handheld devices are far better than movable devices [6, 16]. They are lighter, more useable and have wider communicational accessibility.

For a long time handheld devices were used only as personal tools. They were used for organization of work and keeping of personal notes. Initially, handhelds enabled only the transmission of textual and binary data. The recent advancement in technology enabled taking the handhelds to the next level which enables context sensitivity, transmission and limited display of medical images [3, 7, 8]. Handheld devices processing and memory capacities, display resolution and mobile networks speed have increase. They can now display more levels of gray which is very important for medical imaging [8]. Yet, this is still not enough to incorporate the handheld devices inside conventional PACS (Picture Archiving and Communication System), especial not as equal to stationary or even movable devices. The JPEG2000 features can overcome the limited capabilities of handheld devices making them an integral part of PACS.

3. JPEG2000 features for ubiquitous healthcare

Digital medical images tend to be large in size and storing/network demanding [13]. The complete annual volume of medical images in a modern hospital easily reaches 10 Terabytes. Also, PACS requires Gigabit/s or 10 Gigabit/s bandwidth network. For example, a typical digital X-ray image can be 2Kx2K grayscale image represented with 12bpp which means that the medical image would be about 50 megabits [11].

These requirements are too demanding for handheld devices and mobile networks. Even on 3G networks the complete transmission of the medical image of 50 megabits will last for almost half a minute [5]. This time is accurate only if the handheld device is stationary and close to the provider antenna. The complete image download will take even longer if the handheld device is in the movement.

The biggest issue in using handheld devices for ubiquitous healthcare is display resolution of handheld device and number of gray levels it can provide [8]. Although the hardware of handheld devices advanced, display size did not change much. This is understandable because increasing the size of handheld display will also increase the size of the device itself, decreasing the portability of the device [5]. The resolution of the handheld device display increased over the years but not so much. The average resolution is about 480x320 pixels and 150 ppi. Of course, there are handhelds with higher resolution, but there is only as much differences as human aye can perceive on a small area [5].

This limits the handheld device on displaying the medical image in low resolution or only a portion of the medical image in original resolution. For example, to display a standard MR image of 512x512 pixels on 320x240 display resolution it is necessary either to scale the image to display resolution or to display the 320x240 portion of the image, figure 4. This all gets more complicated with 2Kx2K digital X-ray images. The best course of action (zoom&scroll) is to display the image in low resolution fitted to display size and resolution. User would then zoom in the image to original resolution and scroll the image view to the region of interest.

Because of the size of the medical image, only limited numbers of full sized images can be held in the memory of handheld device [8]. Although the memory capacity can be increased with expansion cards, these cards usually have reduced data access. When another medical image is requested the current image in use is usually discarded.

The zoom&scroll action has several limits when used with default medical imaging formats such as DICOM (Digital Imaging and Communication in Medicine). In DICOM format image remains uncompressed. To display the image, even in the lowest resolution, it is still necessary to transmit the entire medical image. The network communication channel and memory of the

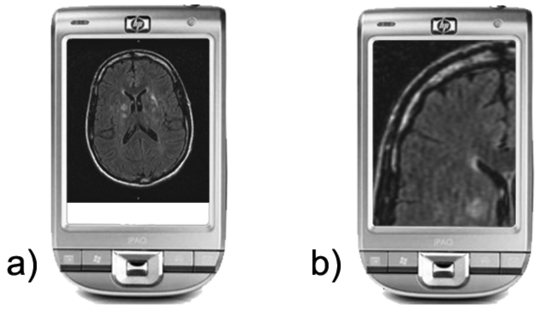

Figure 4. Two ways to display medical image on handheld device: a) image scaled to display resolution; b) a portion of image displayed in original resolution

handheld device are overburden thus the overall transmission time becomes critical [5]. It is necessary to receive the entire image codestream before it is displayed. After the codestream is received all the image processing is done on handheld device. The image scaling is achieved on handheld device thus increasing the time needed to display the medical image to the user. Also the scaled image is rarely of the best possible quality because it is achieved by the auto-scale function of a conventional image browser [13]. Every time when user requests the image in different resolution, scaling on handheld device is repeated. If the image is displayed in higher resolution, user has to pan to the desired region of the image. The scrolling operation burdens the handheld device but it is also a very tiring operation for the user.

Image compression reduces the medical image size, relaxing the storage and network requirements [26]. It is employed in almost every PACS, even in those not containing handheld devices. In the case of the zoom&scroll action, simple still image compression reduces only the networking demands. The entire medical image has to be transmitted and then decompressed in memory of a handheld device. The scale and pan operation are performed on the entire decompressed image. The system can still remain sluggish, slow, and in some cases scaled images are of lesser quality. In many cases it is necessary to implement a separate communication system for transmission of medical images to handheld devices [8, 13].

From the currently available standards for still image compression, JPEG2000 is one of the most suitable image compressions for ubiquitous healthcare [11, 12]. It achieves a more superior compression performance than the other image compressions with minimal spatial distortion within decompressed image

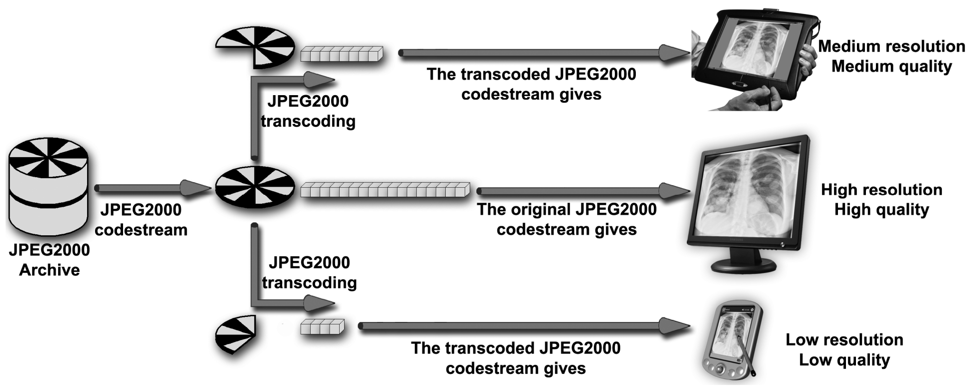

Figure 5. The illustration of JPEG2000 streaming - extraction of a lower-resolution image from one image codestream

[13, 14]. It offers lossless and lossy compression modes, within the same compression process. It supports region of interest coding (ROI coding). Also, JPEG2000 has several features for image protection against errors on wireless networks [25].

The best solution for ubiquitous healthcare human interface of handheld device is achieved when image compression is combined with image streaming which is supported by JPEG2000. The image streaming means that the pixel data needed to represent a part of the image (or the whole image) in a certain resolution and quality are extracted from one stored image codestream and transmitted to the client-side application [13], figure 5. JPEG2000 employs streaming even for losslessly coded images.

As handheld devices are of limited display size and resolution it is not practical to transmit the entire medical image. It is better to send a medical image in size suited for the handheld device processing and display capabilities. When JPEG2000 image streaming is used the same communication system and image source are used to transmit medical images to stationary, movable, and handheld devices. For example, all three different types of devices from figure 5 are served from the same codestream. Only the data needed to view the image in best possible quality and resolution are transmitted. Decompressed images have the best possible quality for the given resolution and compression ratio. The quality is better than the quality achieved by the auto-scale function of an image browser but the minimum data set is used [13].

JPEG2000 streaming simplifies the zoom&scroll action. It makes it faster, more efficient, and friendlier for the user. The JPIP (JPEG2000 Interchange Protocol) part of the JPEG2000 family of standards enables interaction with JPEG2000 content [27]. User can request (a part of) the image in certain quality and resolution. The JPEG2000 zoom&scroll action begins with the low resolution version of the medical image received. Only the data needed to display the image in low resolution suited for display size and resolution is sent to handheld device. Size of the received data is 5 to 10 times smaller than the size of the entire compressed data stream (which is already several times smaller than the uncompressed medical image) [26]. The image is of the best possible quality for given resolution and compression ratio. The transmission of JPEG2000 codestream is progressive, image is displayed very fast while its quality builds gradually. Because the low resolution versions of medical images are of small size, it is possible to store large numbers of these images in the memory of a handheld device.

The low resolution version of the medical image represents only the preview of the image. User can mark a region of the image which is later extracted from JPEG2000 codestream in a higher resolution. This is equal to operation of image zooming. The region requested can be of higher resolution, big enough to fit to handheld device display. The process goes until a region from the image is extracted in original resolution, figure 6. User is freed of unnecessary scrolling, the processing is achieved on server side

Figure 6. JPEG2000 streaming to handheld device – from low resolution version of medical image to region of the image in original resolution

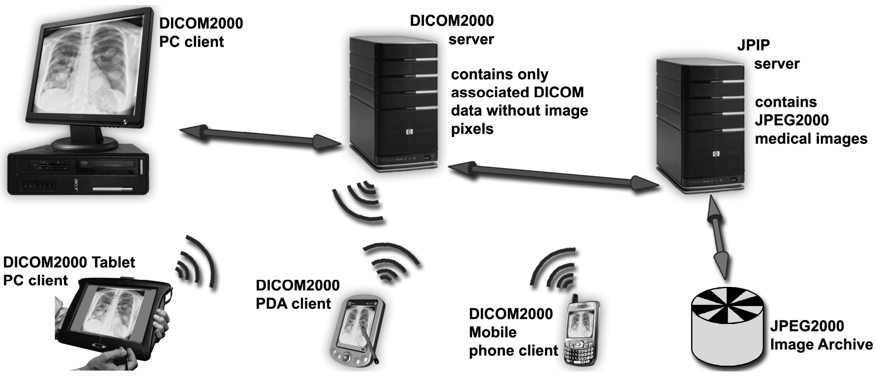

Figure 7. DICOM2000 system – JPEG2000 medical images are stored at JPIP server-side application which is in charge for JPEG2000 transcoding. DICOM2000 clients request medical images through DICOM2000 server

(therefore, it is faster and more efficient), and the optimal data set is used. Only the data needed to display the selected region is transmitted to handheld device. Also, JPEG2000 supports server side data cashing, thus only the data not contained in memory of a handheld device can be transmitted [14, 27]. Although it is not possible to see the entire image in original resolution, it is possible to pan through the image (user navigates through connected regions of the image in original resolution). This enables displaying of medical images even on less powerful handheld devices in acceptable time [9, 13].

We contribute to the field of ubiquitous healthcare with DICOM2000 system [13, 29, 30]. The DICOM2000 system is a PACS based on DICOM2000 syntax, figure 7. It enables the JPEG2000 streaming inside DICOM based networks. As it can be observed from figure 7, handheld devices are integral part of PACS. The same image sources are used to serve stationary, movable, and handheld devices. This system represents a solid ground for telemedicine and ubiquitous healthcare.

4. Issues of User Interface Design for Medical Image Display

Important aspect of ubiquitous healthcare human interface is design for medical image display [8, 9, 25, 31]. This issue is important regardless of the image format used. The interface designed for handheld devices differs from the ones designed for desktop computers because of small display size and interaction techniques used.

Because of their size, the biggest part of the handheld device screen should be used for displaying medical image (as much as possible) [8]. This means that most of the user interface should be conceived in a menu available through a button similar to Windows Start button. Button should be of sufficient size according to Fit's law. If there are too many options for one menu, user interface should be conceived in a menu-bar (but this should be avoided whenever it is possible). Also image width and height sliders and navigation controls should appear only when needed or requested by user. Zoom and pan operations should be implemented as special mode of interface. In pan or zoom mode, all the controls should automatically disappear. This will maximize the screen size for image display. The controls should reaper when user leaves pan or zoom mode.

If there is textual data to display, the most important data should be presented together with the image but only on user request. Data should be displayed on remote part of the screen independent of the image or as image overlay, figure 8. The user should be provided with a way to move the text over screen. Only as the last resort and only if there is too much data covering the entire image should the associated data be presented on multiple or scrollable screens. In that case the first screen should contain the image data and the associated data should be displayed on consecutive screens [9].

When this is possible, the user interface for

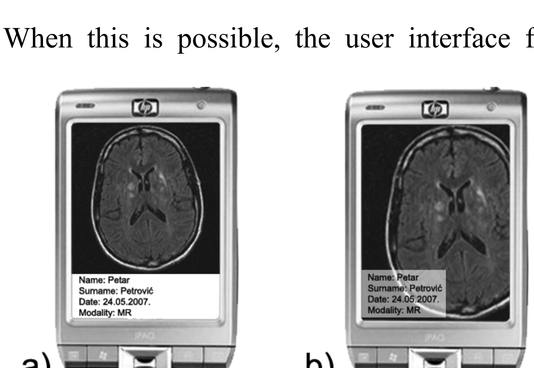

Figure 8. Textual data is displayed beside medical image (a) or overlay medical image (b)

handheld devices in ubiquitous healthcare should contain minimal number of data entry fields [31]. Typing on soft-keyboard of a handheld device is burdensome. Data entry fields should provide data completion. Whenever it is possible the users should be provided with a list of values from which they should choose. The amount of text should be kept to a minimum. The fonts should be large and consistent. Good contrast to the background should be provided. The most important content should be provided first. Because of limited amount of space the textual information should be replaced through representative and familiar icons.

Because most handheld devices have touch-screens, user interface should be adapted for users thumb size because the use of mobile stylus occupies both hands. The different amount of area covered by user's thumb on different parts of the screen should be taken into consideration [32]. Whenever it is possible the image manipulation functions should be mapped to hardware buttons of a handheld device such as scrolling wheels which could replace image width and height sliders and/or pan controls. Therefore it will not be necessary to provide on-screen (software controls) for these functions and the number of on-screen functions will be minimized [8]. The most important guideline is to keep the user interface for handheld devices in ubiquitous healthcare as simple as possible [31].

User interface of handheld device for ubiquitous healthcare should be adaptive to user role and user task, and context (ambient) sensitive. Devices are not personal in ubiquitous environment. Different users, with different rights and jobs, may use the same the device. For example, when nurse uses the handheld device only the options she is entitled for should be available. She should be able to enter information about medication, patient nutrition, etc, but she should not be able to give diagnosis. On the contrary physician should be able to view and change the diagnosis, schedule new tasks, and patient treatments. This should be achieved through technologies which enable adaptive user interface such as XAML (eXtensible Application Markup Language) [33]. User interface should be adaptable to accommodate user environment. If the handheld device is used inside radiology department it should be able to display data from radiology.

5. Conclusion

Although the ubiquitous healthcare represents intensive research area, it has not yet reached the full-scale commercial implementation and use. Recent innovations in hardware and software technologies of handheld devices enable them to become part of ubiquitous healthcare. Because they are light, portable, and ever connected to communication network, handheld devices can be carried in pockets making their user full time part of ubiquitous healthcare environment. These devices enable healthcare personnel to transmit and receive medical data regardless of the time and place they are. User interface of handheld devices can adapt to the context of the working environment and to the current user.

Although it is possible to send and display medical images on handheld devices, this is a very slow, demanding process. Usually it is achieved on separate communication system dedicated to handheld devices. Only a limited number of medical images and limited types of medical images (which are of low resolution) can be displayed. To improve medical image display on handheld devices and to truly achieve ubiquitous healthcare it is necessary to apply medical image compression and streaming. This could be achieved by JPEG2000 still image compression. It employs image streaming even for losslessly coded images. In combination with JPIP communication protocol, JPEG2000 forms an environment for medical image exchange suitable for ubiquitous healthcare. The same communication system and source of medical images is used to serve stationary, movable, and handheld devices. Therefore, the overall performance is increased while minimizing the cost of a healthcare system.

Handheld devices and JPEG2000 enable transmission and medical image display in usable way. Only the data needed to display the image in requested resolution are transmitted. The transmission is fast even on low-band networks. It is possible to gradually build up the resolution and quality of the medical image. Through pan operation, it is possible to display regions of the image in original resolution and quality. Users are freed of needless scrolling of medical image. All the requests of the client are served from the same image codestream and all the hard processing is done at server side. Because the requirements for handheld devices are minimized, even the most common handhelds can be used for ubiquitous healthcare.

We have incorporated inside DICOM2000 system some of the presented ideas and possible uses of JPEG2000 in ubiquitous healthcare.

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