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A PDA - BASED TELERADIOLOGY SYSTEM

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Abstract. *The use of a Wireless Local Area Network (WLAN) for the transmission of a high quality medical signal, either static or animated, is of extreme interest, especially when the final display medium is a PDA (Personal Digital Assistant), a very light and compact handheld device. This paper describes the development of applications that are responsible for receiving and displaying medical images.*

1 INTRODUCTION

Wireless local area networks (WLANs) are currently being used in a wide area of applications, including medical imaging. The reasons behind the vast popularity of WLAN-related applications are mostly related to the inconvenience caused by cables involved in wired LANs, as well as common networking portability problems.

Wireless networking nowadays offers satisfying transmission data rates over a wide cover range. Furthermore, it is resistant to external interferences caused by other wireless devices in close vicinity, while security in data transmission is satisfactory **[1]**. The protocol that fulfills all the above statements and was used in the present study is the IEEE 802.11b.

Research is already underway on the major issue of how patients may use such WLAN services, even in the absence of physicians. One such project is "MedLAN" **[2]**.

On the other hand, the small size and weight of PDA devices offer extreme portability and convenience. Their most common use is keeping notes, scheduling tasks and the contacts of the owner. However, with the rapid evolution of electronic technology, PDAs are now capable of accomplishing far more sophisticated and demanding tasks, such as reproduction of video sequences and processing of static high quality medical images. They are also capable of establishing connections to wireless networks and take full advantage of their potentials.

2 MATERIALS AND METHODS

A related research, regarding specific characteristics of a wireless teleradiology application, was conducted in Spain and in Germany in 40 physicians **[3]**. Their field of expertise is imaging, while most of them work at radiology departments. The results of this research were as follows:

- The displayed image should meet the minimum resolution of at least 256x256 pixels up to 512x512 pixels and 12bit grayscale depth.
- The display does not necessary have to be in color. However, it should be able to display an adequate range of grey levels.
- An increase of the device weight was preferred in favor of larger screen sizes.
- The Level/Window procedure is mandatory and therefore it has to be performed in seconds or less.
- A lossy compressed image is acceptable, even with visible effects.
- A 512x512 image of a 12bit depth should be transmitted within 10 seconds and not above 20.
- The preferred input method is the stylus.

In relation to the above specifications, special PDA software for transmitting and receiving over WLAN was developed in MEDISP (Medical Image and Signal Processing) Lab of Technological Institute of Athens. The software packages used for developing the final application include:

- Microsoft Embedded Visual Tools 3.0 including Visual Basic and Visual C++ (High Level Software Development and Compiler)
- Microsoft Pocket PC SDK (Software Development Kit)
- Microsoft Windows Media SDK

The application was developed on a typical desktop PC (Intel Pentium 4 / 1,8GHz with 512MB RAM) running Microsoft Windows 2000.

The hardware platform chosen for the final prototype was the Compaq iPaq 3630 combined with D – Link IEEE 802.11b compliant wireless card DCF-660W. The device features a 200MHz Intel Strong-Arm Processor, 32 MB SDRAM, 16 MB Flash ROM, a Compact Flash Card expansion slot for optionally adding extended memory capabilities and a 3.8" 240x320 16-bit color TFT display with backlight. The operating system is the Microsoft Pocket PC 2002 **[4]**.

2.1 Image Viewing

The PDA application can load a wide variety of images, whether they are color (RGB) or Grayscale of the following formats: DICOM, BMP, JPG, GIF, PNG and TIFF **[5]**. It can also save the opened images in BMP, JPG, GIF and in PCX formats. It can open practically any size of image, but the maximum visible resolution is limited to 240 x 240 pixels. Images larger than 240 x 240 can also be viewed using a special 'Shrink to Fit' function **[Fig. 1]** that employs the appropriate zoom factor, so that the original image fits in a 240 x 240 frame. If the 'Shrink to Fit' function is not used, the user has the ability to scroll the image (using the stylus) in its original size. This function is called 'Tap & Scroll'. There is also the option to zoom as well as full screen viewing. The feature of rotating an image, in angles multiples of 90^{o}, is also supported. Finally, standard mirroring and flipping image transformations are supported.

Figure 1. Image Viewing with 'Shrink to Fit' Function Activated

2.2 Image Processing

The application can process the loaded images using special-purpose algorithms to enhance image quality. One of the most commonly used image enhancement method is the "windowing correction" technique **[Fig. 2]**, which is used in the application in two ways: (a) by window-width and window-level adjustment using two slider bars and (b) by stylus movement, for adjusting image brightness and contrast. In addition, the application uses image enhancement techniques for (a) contrast enhancement by means of histogram modification (Cumulative Density Function based Histogram Equalization) **[Fig. 3]**, (b) typical 2-dimensional convolution filtering, including smoothing, laplacian, high emphasis and unsharp **[6]**, and (c) adaptive median filtering for de-speckling of ultrasound images **[7]**.

Algorithms were designed in a robust and compact way, in order to comply with the PDA's CPU efficiency, and further minimization of the processing time.

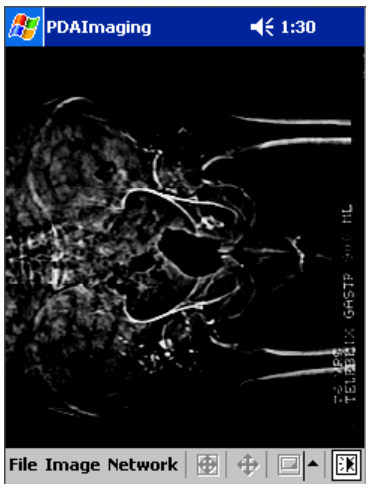

Figure 2. Windowing Correction Technique

Figure 3. CDF Equalize Function

Figure 4. Invert Colors Function

2.3 Regions of Interest (ROI)

The PDA application has the ability of drawing regions of interest (ROIs) on the image and presenting relevant information in pixel measurements, such as surface area, mean value and standard deviation **[Fig. 5]**. There is also the capability of measuring distances between two image points (Point to Point Distance) **[Fig. 6]**.

Figure 5.Region of Interest

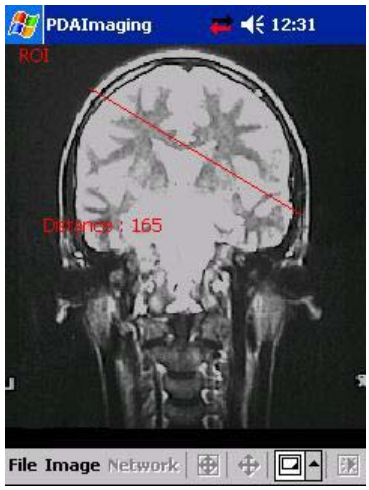

Figure 6.Point to Point Distance

2.4 Networking

Taking full advantage of the wireless networking card, the PDA application can connect to a central computer (server) and download new images from a shared folder, which can be updated at any time with new folders containing image files. During any folder updates, the PDA user receives a notification pointing out the updated network folder **[Fig. 7-8]**. The file transfer times are proportional to the image size, e.g. at 3Mbps, a 500kb image takes less than 4s to download. However, the actual transferring time depends on the network speed, as specified by the IEEE 802.11b protocol **[8]**.

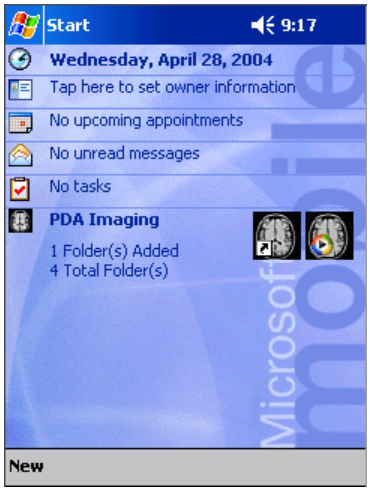

Figure 7. Shared Folder Update Notification

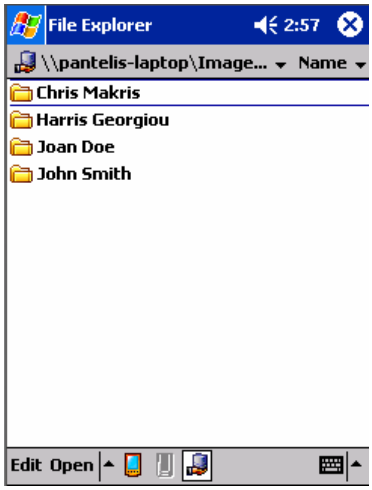

Figure 8. Shared Folder View

2.5 Other Features

Several other important features have also been included, such as (a) presentation of the image histogram **[Fig. 9-10]**, i.e. pixel distribution per gray tone and per chromatic channel for color images, and (b) DICOM-header saving into plain text file, for filing purposes.

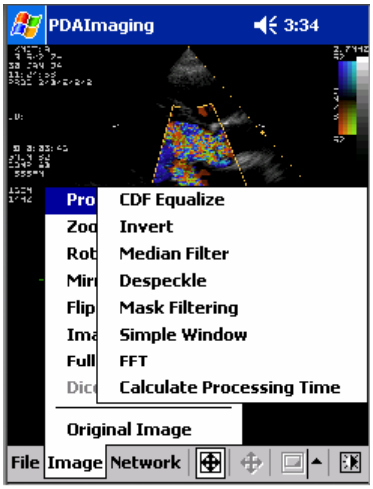

Figure 9. Image Processing Options for a Color DICOM Image

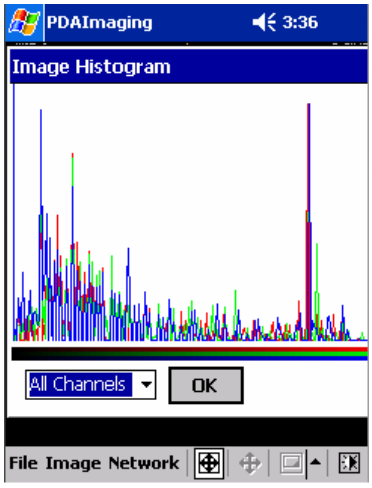

Figure 10. Histogram Plot for a Color DICOM Image

2.6 Video Client Operation

The PDA application has the ability to operate as a networking client and connect to a server that provides access to a live video stream. For the implementation of this feature, a part of Windows Media Technologies was used. On the server's side, the basic requirement is the presence of windows media encoder software. With this

server-client software combination, the user is receiving a 'drop frame'-free stream of desirable image size up to 240x270 pixels and standard audio quality **[Fig. 11]**. The average number of frames per second (fps) in most cases was approximately 20fps, while 15fps was evaluated as the lowest acceptable limit, in terms of image quality, by the expert physician. In order for the whole procedure to be carried out efficiently, a standard pre-buffering technique is used, although it leads to an undesirable 6-sec delay, including encoder latency. The time-to-connect is approximately 4 seconds depended on the current network load and the server status.

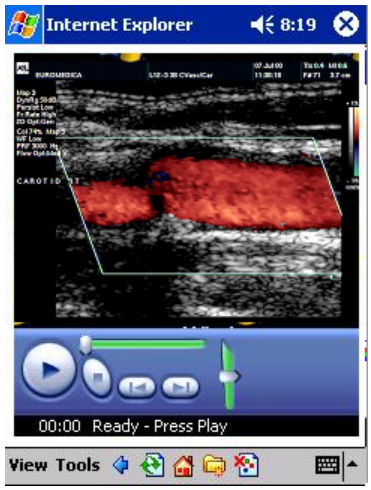

Figure 11. Carotid US Preview in Video Client Operation Mode

One great advantage of this whole procedure is the flexibility in the settings of the desirable frame rate, image resolution, video and audio bit rate and codecs. Any of these settings can be saved as a user profile and be used again in the future. The particular network configuration can host unlimited clients. Furthermore, the server has a variety of security settings, most important of which is the ability to drop undesired clients by scanning their IPs.

3 RESULTS

Modern PDA handheld devices, combined with wireless networking technology, advanced operating systems and sophisticated image processing techniques, can be used for modern medical teleconsultation within a hospital environment. Portable small weighted devices, capable of running special purpose applications have been proven to be valuable tools for preliminary diagnostic evaluation by physicians. The system meets the initial specifications regarding the user requirements for a wireless teleradiology application, both for still image viewing and for video stream.

Static image viewing has been evaluated as adequate by the expert physician, although the screen size is much smaller than a desktop computer. The viewing quality of grayscale images was satisfactory and can be further enhanced by the use of the integrated image processing algorithms (windowing, filtering, denoising, etc.). Full DICOM decoding support for image files makes the application plausible for a modern hospital environment. The video client operation mode has been proven sufficient for preliminary analysis and monitoring for animated medical application (ECG/EEG traces, ultrasound, etc.). Measured network latency and encoder's overhead times have been evaluated as acceptable and within the specified operational requirements.

The use of new generation wireless network technologies, such as IEEE 802.11g (55Mbps) instead of 802.11b (11Mbps), can further improve the transfer speed and client capacities. The security of the medical data is ensured with the employment of special remote access technologies, such as Wired Equivalent Privacy (WEP), Service Set Identifier (SSID) and server logon (user name/password). For advanced security requirements, specialized data encryption protocols, such as IPSec or SSL (Secure Socket Layer), can be integrated on both the server and the client side.

4 CONCLUSION

By exploiting state-of-art technology, a PDA-based teleradiology wireless application for image and video transmission was designed and proved plausible for application in a hospital environment. This was made possible by employing mobile telecommunications technologies currently part of everyday life for millions of people.

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