A SMARTPHONE-BASED TELERADIOLOGY SYSTEM

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The development of a teleradiology application for remote monitoring and processing of patient image data using 2nd generation mobile devices with enhanced network services, is of extreme interest, especially when the final means of display is a smartphone, a very light and compact handheld device. In the following paper the development of applications, that are responsible for remote monitoring and processing of medical images, is investigated.

1. INTRODUCTION

Modern wireless technologies have enabled mobile users to communicate using voice, still images and text messages. However, current advances in electronics and microprocessor technologies are more than adequate for computational-demanding tasks like basic image processing and video streaming.

Second generation mobile telephone networks are widely spread and available throughout the world. The introduction of GPRS (General Packet Radio Service) in this wireless environment provides access to improved data transfer speeds currently up to 171Kbps **[1]**, expected to increase even more with the acceptance of third-generation mobile technologies.

Improved mobile device capabilities, combined with enhanced networking services and transfer speeds, can offer practical teleradiology applications for the working physicians, where remote access to high quality medical images and video monitoring is extremely important.

2. MATERIALS AND METHODS

The hardware chosen for the present study was the Motorola MPx200 that features a Texas Instruments 120 MHz processor, 32 MB RAM, 32 MB ROM, a Secure Digital Card expansion slot for optionally adding extended memory capabilities and a 176 x 220 16-bit color TFT display with backlight. The operating system is the Windows for Smartphone 2002 edition **[2]**.

The software packages used for developing the final application include:

- Microsoft Embedded Visual Tools 3.0 including Visual Basic and Visual C++ (Software Development Environment and Compiler).
- Microsoft Windows SDK for Smartphone 2002.
- 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.

Image Viewing

The smartphone application can be used to load a wide range of image formats, including: DICOM, BMP, JPG, GIF, PNG and TIFF, color (RGB) or Grayscale **[3]**, as well as save the opened images in BMP, JPG, GIF and in PCX formats. The maximum visible resolution that matches the device's display square size is 176x176, although the application can load practically images of larger sizes that can be viewed. The user has the option to scroll the viewable region using the 4–way navigation key, so that the display shows a particular area of the image in its original size. Alternatively, he can use the 'Shrink to Fit' to resize the visual dimensions of the image, so that it fits within the device's display boundaries **[Fig. 1]**, or he can selectively zoom in with greater zooming factors. The image can be rotated in angles multiples of 90^o, while standard mirroring and flipping image transformations are also supported.

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

Image Processing

Image quality can be enhanced using standard image processing algorithms specialized in common medical applications, including the "windowing correction" technique that adjusts grayscale mapping for higher image contrast, using the 4–way navigation key. In addition, the application employs more advanced image enhancement techniques **[4]** for (a) contrast enhancement by means of CDF histogram modification (Cumulative Density Function based Histogram Equalization) **[Fig. 2]**, and (b) standard 2-D convolution filtering, including median **[Fig. 3]**, smoothing, laplacian, high emphasis **[Fig. 4]** and unsharp masking. Finally, the complete color map can be inverted, resulting in the corresponding negative image **[Fig. 5]**. Algorithms were designed in a robust and compact way, in order to utilize the smartphone's CPU and memory resources as optimally as possible.

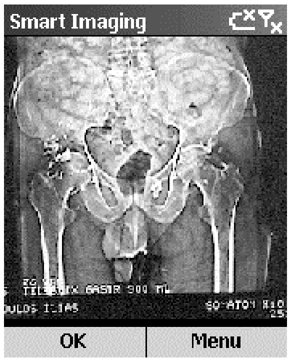

Figure 2. CDF Equalize Function

Figure 3. Median Filtering Function

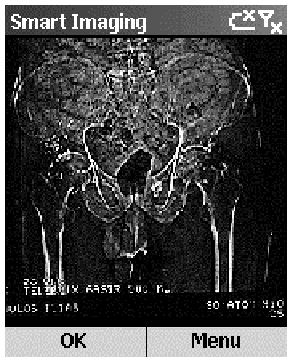

Figure 4. High-Emphasis Filtering Function

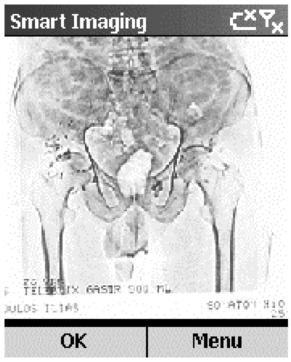

Figure 5. Invert Colours Function

The user interface of the whole application has been designed and implemented in a simple, elegant way in accordance to the operating environment of the smartphone itself **[Fig. 6]**. Other processing features already available, including histogram and spectrum display, are currently under optimization for minimal resource requirements and processing times.

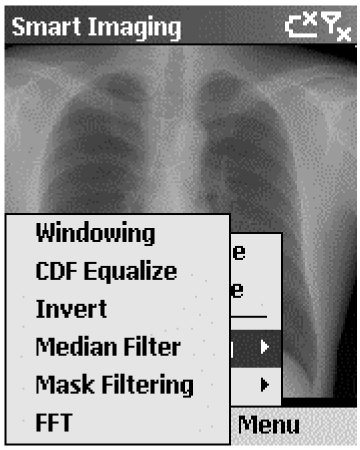

Figure 6. Image Processing Menu

Networking

Taking full advantage of the wireless networking services, the smartphone application can connect to a central computer (server), using any compliant FTP client module **[5]**, and download new images from a secure FTP folder, which can be updated at any time with new folders containing image files. The file transfer times are proportional to the image size, e.g. a 500kb image takes roughly 30s to download in typical GPRS network operating conditions, although the actual transferring times are dependent on the current network load, as described by the GPRS specification **[6]**.

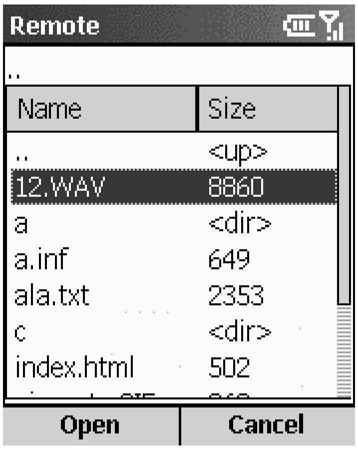

Figure 7. FTP Client View

Video Client Operation

The smartphone application has the ability to automate the Windows Media Player to connect to a streaming server (video encoder) that provides access to a live video stream, exploiting a part of Windows Media Technologies. On the server side, Windows Media Encoder software is required for video streaming. This server-client software combination enables the user to receive a stream of frame size up to 170x150 pixels and standard (voice) audio quality **[Fig. 8]**. The average number of frames per second (fps) in most cases was approximately 15 fps, which has been evaluated as adequate by the expert physician in terms of image quality. For efficient and uncorrupted data streaming, the encoder employs a standard pre-buffering technique that it leads to a 6-sec delay, including encoder latency. The connection initialization delay (time-to-connect) is approximately 4 seconds, dependent on the current network load and the server status.

Figure 8. Preview in Video Client Operation Mode

3. RESULTS

Modern smartphone devices, combined with GPRS mobile network services, modern operating systems and sophisticated image processing techniques, can be used for 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.

Static image viewing has been evaluated as adequate and, according to the expert's opinion, the viewing quality of grayscale images was satisfactory and can be further enhanced by the use of the integrated image processing algorithms. DICOM decoding support for image files makes the application plausible for teleradiology applications. The video streaming feature has been proven sufficient for preliminary clinical analysis and monitoring in medical applications (ECG/EEG traces, ultrasound, etc.). Measured network latency and encoder's overhead times have been estimated as acceptable and within satisfactory operational requirements.

The generation of new wireless network technologies, such as EDGE (Enhanced Data for Global Evolution) **[7]**, operating at 384Kbps, instead of GPRS, operating at 171Kbps, can increase the data transfer speeds and client module capabilities. The security of the medical data is supported by (a) relying in the internal security of the GSM system **[8]**, (b) full logon procedures for remote file access via standard FTP and (c) by optionally deploying a secure FTP server (SFTP) for maximum security during data transfers. For even higher security, modern protocols like IPSec ensure data integrity and access control at the network layer.

4. DISCUSSION

The combination of smartphone technology with specialized medical applications has proven extremely valuable in modern hospital environments. The processing time for typical image filtering functions has been evaluated as acceptable in all cases. More computation demanding tasks, like FFT spectrum calculation, can be accommodated to provide the best possible results within the limited resources of the device. Video streaming quality was also acceptable for typical monitoring by an expert physician, even at moderate to low frame rates.

The application itself is capable of using any image file stored locally in the memory, while at the same time the smartphone itself provides numerous means of accessing remote data content. Instead of FTP access, any other file-access protocol can be used to acquire, download and store images locally. For example, a web-enabled device can use any web browser to access a HTTP server that stores medical image material.

Although GPRS provides upper speed limits up to 171Kbps, in practice only a portion of this theoretical bandwidth is available to the end-users. In most experimental cases, maximum transfer times were calculated around 30 sec for 512x512 images of 8bit greyscale, acceptable in most medical applications **[9]**.

5. CONCLUSION

A smartphone-based teleradiology application was designed for remote video monitoring and still image processing. Similar mobile applications, implemented by employing modern wireless telecommunications technologies, extend the existing preliminary clinical practices in modern healthcare environments.

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