2nd International Conference "From Scientific Computing to Computational Engineering"
2nd IC-SCCE
Athens, 5-8 July, 2006

PDA-BASED TELERADIOLOGY SYSTEM WITH REAL-TIME VOICE CONFERENCING CAPABILITIES

Pantelis Georgiadis [1], Konstantinos Sidiropoulos [1], Chrisovaladis Hikimtzis [1], Konstantinos Banitsas [2], Nikos Dimitropoulos [3] and Dionisis Cavouras [1].

[1] Medical Image and Signal Processing Lab., Dept. of Medical Instruments Technology, STEF,
Technological Educational Institution of Athens,
Ag. Spyridonos Street, Egaleo, GR-122 10, Athens, Greece.
email: *cavouras@teiath.gr*, web page: http://medisp.bme.teiath.gr/

[2] Department of Electronic & Computer Engineering, Brunel University, Uxbridge, UB8 3PH, UK, e-mail: *bany@hol.gr*

[3] M.D., Ph.D., Medical Imaging Department, EUROMEDICA Medical Center, 2 Mesogeion Avenue, Athens, Greece.

Keywords: teleradiology, PDA, VoIP, mobile.

Abstract. *During the past few years, the healthcare sector, where the need for precise and rapid delivery of information is of vital importance, could not remain unaffected by the latest developments in modern mobile and wireless devices. The aim of the present study was to design and implement a Personal Digital Assistant (PDA)-based teleradiology system incorporating mobile real-time tele-consultation facilities. The PDA application software was developed using MS Embedded Visual C++ 4.0. Each PDA (HP iPaq hx2410) can perform and receive voice calls from a compatible client (PC or PDA), utilizing the ITU-T's H.323 Voice over IP (VoIP) protocol. Additionally, the user can receive, load and save hi-quality static images as well as process and perform size and area measurements on the images during a voice-call, which may include more than 2 participants. The codec used for the voice-calls was the G.711 A-Law. The developed application combines static hi-quality image displaying and processing, with voice-enabled conferencing capabilities, rendering the system a totally mobile medical teleconsultation tool.*

1 INTRODUCTION

The increased use of mobile devices, Personal Digital Assistants (PDAs), and wireless devices in general, has metamorphosed during the past few years the way we perceive things around us and has had a radical impact on our working environment. The healthcare sector, where the need for precise and rapid delivery of information is of vital importance, could not remain unaffected by these developments.

The way for wireless transfer of real time video, audio, and information has been recently opened up by ongoing research projects[1]. In spite of the autonomy that such developed systems provide to the healthcare personnel operating within clinical departments, such as the Accidents & Emergency (A&E) department, the need for mobility in the consultant's site is still essential. This need arises mainly from the fact that consultants have to frequently move from one ward of the hospital to another, and therefore they are hardly ever in a fixed position. Additionally, there should exist a way of enabling the consultant to have access to the patient's information while being away from the hospital and thus effectively help on delivering a diagnosis as accurate as possible.

The use of portable PDAs along with wireless LANs can satisfy the aforementioned need. Currently, the small size and weight of PDA devices provide tremendous convenience and portability. Furthermore, with the rapid evolution of electronic technology, PDAs are now capable of accomplishing more challenging tasks, such as reproduction of video sequences and processing of static high quality medical images[2].

In addition, modern PDAs are also capable of connecting to both wired and wireless networks and fully exploit their potentials. A wide variety of applications, including medical imaging, take advantage of wireless local area network technology. The reasons behind the vast popularity of WLAN-related applications are mostly associated to increased portability as opposed to the case of wired LANs.

Moreover, the technological fusion of modern PDA handheld devices, wireless networking technology and image processing techniques, can provide the solution to modern medical teleconsultation within an all-wireless digital hospital environment[3].

The aim of the present study was to propose an all-wireless environment for teleconsultation: from the clinical department of the hospital (using mobile computers and WLANs) to the consultant (using PDAs and WLANs), all healthcare personnel should be allowed freedom of movement.

The proposed system overcame the problem of the mobility in the consultant's site by introducing real time image and voice services on PDAs. The system, employing sophisticated algorithms and protocols, enabled the users to perform and to receive voice calls while at the same time to review and process medical images. This feature assisted physicians in applying state-of-art, real-time, rich media telemedicine. For the transmission of the voice, the system used the H.323 protocol, which is a well-established VoIP protocol[4]. For the medical image transmission and viewing, the system conformed to the DICOM protocol, providing full decoding support for the most popular transfer syntax UIDs[5].

2 MATERIALS AND METHODS

The system comprised two software applications, the VoIP module and the teleradiology module. These two PDA-based applications were integrated to form the final teleconsultation system. The software packages used for developing these modules were: a/ Microsoft Embedded Visual C++ 4 (High Level Software Development Environment and Compiler) and b/ Windows Mobile 2003 Software Development Kit (SDK). The application was developed on a typical desktop PC (Intel Pentium 4 @ 3 GHz with 1GB RAM) running Microsoft Windows 2000.

The hardware platform chosen for the final prototype of this project was the HP iPaq rx3715. The device features a 400 MHz Samsung S3C2440 Processor (ARM compatible), 64 MB SDRAM, 128 MB Flash ROM, a Secure Digital Card expansion slot for optionally adding extended memory capabilities and a 3.8" / 89-millimetre diagonal 240x320 16-bit color TFT display with backlight. It also offers WiFi connectivity through its integrated IEEE 802.11b compliant wireless network card as well as Bluetooth connectivity. The operating system was the Windows Mobile 2003 SE.

The architecture of the system **[Fig. 1]** consisted of lightweight PDA devices that the consultants carried with them while roaming around the hospital, the image servers, where the patient images are stored, and finally a base station, from which the voice stream was transmitted. The image servers were integrated with the existing Picture Archiving and Communication System (PACS) of the hospital. The base station was a laptop computer equipped with a microphone. All the devices were connected together using WLAN technology through properly installed access points that covered the desired hospital area. The consultants communicated with each other using their PDAs as well as with the base station. By using special purpose software, called Multi Point Controller Unit (MCU)[4], more than two users could collaborate at the same time by talking to each other, and reviewing the same images.

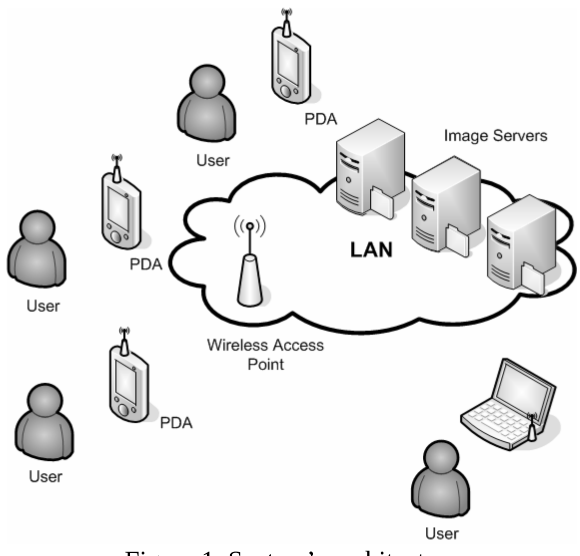

Figure 1. System's architecture

2.1 VoIP module

The VoIP module is an implementation of the H.323 protocol for the Windows Mobile operating system. During the development of the module, two open source libraries were used in order to speed-up the development process. These libraries are the PWLib and the OpenH323Lib and they are distributed freely under the Mozilla Public License (MPL)[6]. The module also has a friendly GUI that enables the user to perform and to receive voice calls easily. As far as the transmission of voice is considered, the application employed the G.711 codec, a coding algorithm that converts analogue voice to digital bit stream using a source sampling rate of 8 KHz and resolution of 8 bits per sample[7].

Once the module is running, it is capable to perform voice calls with other H.323 compatible endpoints. At the same time, it listens for incoming calls. When a request for an incoming call occurs, the user is notified with a sound tone. If the user accepts the incoming request, the collaboration begins.

On the other hand, when the user enters a valid IPv4 address and presses the call/answer button, the module reaches the endpoint requested. Through the signaling channel, the module receives the current status of the remote endpoint and informs the user, using sound tones, about its availability. When the remote user accepts the call, the collaboration begins.

2.2 Teleradiology module

The teleradiology module 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. It can also save the opened images in BMP and JPG 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 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.

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, 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), b/ typical 2-dimensional convolution filtering, including smoothing, laplacian, high emphasis and unsharp[8], and c/ adaptive median filtering for de-speckling of ultrasound images[9]. 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.

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.

2.3 Integration among modules

The VoIP module developed can be accessed through the teleradiology application’s menu and vice versa. The two modules can run simultaneously. When the VoIP module is minimized, the user receives notification about its status **[Fig. 2]**. The notification is a pop-up window that informs the user about the current status of the VoIP module and prompts for an action (e.g. answer or decline an incoming call). The user can simultaneously talk and display medical images as well as process them. The VoIP module was designed in such way that it leaves enough processing resources to perform the basic image processing procedures, such as windowing or mask filtering.

3 RESULTS

A prototype of the system was tested in a real healthcare environment and received very positive remarks from both the treating physicians and the consultants, as it allows for easier, more reliable, faster and cheaper teleconsultation[3].

The prototype system consisted of a PDA device running both the VoIP and the teleradiology modules. The consultant used the PDA while roaming around the hospital's A&E department. The base-station and the image server were typical personal computers (a laptop and a desktop pc respectively). The base-station was equipped with an external microphone, which provided the audio feed. It must also be noted that the voice transmission was realized by an H.323 compatible application (NetMeeting) running on the base-station. The image server held testing DICOM images, selected for the purposes of the evaluation.

The clinical department, where the experiment took place, was covered with WiFi using two IEEE 802.11b compliant access points (APs), providing wireless access to any authorized client inside their cover range. The sites of the APs were carefully selected to ensure the maximum cover range. The electromagnetic signals of the AP's were considered not to interfere with the existing biomedical equipment[10].

For efficient operation, the VoIP module required network bandwidth up to 64 kbit/s[7]. The sound delivered, was lacking any degrading effects such as voice interruption or echo. The jittering and echo cancellation techniques employed[11], played a major part in improving the sound quality. Even in an environment full of ambient sounds and noise, like the healthcare department of a hospital, the system demonstrated a very satisfactory sound performance mainly due to the utilized adaptive noise reduction algorithm[11]. Moreover, the voice detection algorithm assisted in reducing the bandwidth occupied by the module, by interrupting voice transmission when the input voice signal does not exceed a constantly adaptive threshold.

Regarding the teleradiology module, static image viewing has been evaluated as adequate by the expert physician (D.N.), 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 processing time for typical image filtering functions has been evaluated as acceptable in all cases. To overcome the PDA's low efficiency CPU, algorithms were efficiently designed so as to minimize processing time. Most of the algorithms exhibited acceptable performance regarding their processing times.

The file transfer times were measured to be proportional to the image size, e.g. at 3Mbps, a 500kb image took less than 4s to download. However, the actual transferring time, depended on the network congestion and speed, as specified by the IEEE 802.11b protocol[12]. 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 integration of the VoIP and the teleradiology modules enabled the consultants to perform and to receive voice calls while at the same time to review and process medical images. The simultaneous execution of both modules did not have any considerable impact in the achieved processing times.

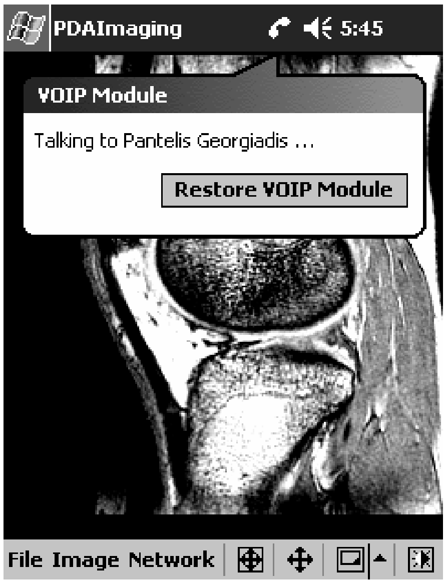

Figure 2. The VoIP and the teleradiology modules working together

Both modules run on the application layer of the TCP/IP protocol suite[13]. As a result, the application can cooperate with any IP-based network protocol such as General Packet Radio Service (GPRS)[14] and Universal Mobile Telecommunications System (UMTS)[15].

The security of the medical data was 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)[16].

Furthermore, for the security of the voice calls, the integrated H.323 security protocol was employed (H.235)[17], providing user authentication and privacy of transmitted voice[4]. For advanced security requirements, specialized data encryption protocols, such as IPSec or SSL (Secure Socket Layer), can be integrated on both the base-station and the client side module[18].

4 DISCUSSION

The developed system was designed to run on the application layer of the TCP/IP protocol suite. As a result, it can cooperate with any IP-based network protocol such as GPRS and UMTS, as long as there is a compatible network card installed on the PDA, or internal support of such networks by the PDA. Moreover, the application is functional even when the underlying connection protocol changes on-the-fly (from WiFi to GPRS/UMTS and vice-versa). This permits the user to either use WLAN connection when he/she is around an area with WiFi support or be truly mobile with GPRS/UMTS connection when he/she is outside the coverage of any WLAN. This property renders the system truly mobile, delivering to the healthcare professionals access to clinical data from practically anywhere. However, despite the fact that the system can collaborate with any IP-based network, initial tests were done using just the IEEE 802.11b environment.

Regarding future work, implementation of additional and more sophisticated image processing and analysis algorithms is under investigation. One of the most serious drawbacks of this undertaking is the limited processing capability of PDA devices due to the lack of a Floating Point Unit (FPU). The solution to this limitation could be the exploitation of teleprocessing systems, where the mobile device would assign computationally demanding tasks to a network of processing units.

Another idea for future work could be the implementation of one way (from base-station to PDA) or even two-way video transmission along with the voice transmission. The H.323 protocol stack used, already supports video transmission through several coding schemes such as H.261 and H.263[19]. Moreover, modern PDA devices embed a digital camera, enabling them to capture both images and real time video streams. Taking full advantage of this feature, a future version of the system could support bidirectional video-calls.

5 CONCLUSION

Modern PDA handheld devices, combined with wireless networking technology, advanced operating systems and sophisticated image processing and voice transmission techniques, can be used for modern medical teleconsultation within an all-wireless digital 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 aim of this project was to propose an all-wireless environment for teleconsultation: from the clinical department of the hospital to the consultant using personal digital assistants. The proposed system overcame the problem of the mobility in the consultant’s site by introducing real time image and voice services on PDAs. The system, employed sophisticated algorithms and protocols, that enabled the user to perform and to receive voice calls while at the same time to review and process medical images. This feature assisted physicians in applying state-of-art, real-time, rich media teleconsultation.

REFERENCES

[1] Istepanian R.S.H., Tachakra S., Banitsas K. A. (2001), Medical Wireless LAN Systems (MedLAN). State of the Art, Challenges, and Future Directions, eHealth conference, City University

[2] Georgiadis P., Banitsas K., Georgiou H., Sidiropoulos K., Tachakra S., Dimitropoulos N., Cavouras D. (2004), A PDA-Based teleradiology system, 1st International Conference “From Scientific Computing to Computational Engineering” (1st IC-SCCE)

[3] Banitsas K. A., Georgiadis P., Tachakra S., Cavouras D. (2004), Using handheld devices for real-time wireless Teleconsultation, IEEE EMBC 2004, pp. 3105-3108

[4] Kumar V., Korpi M., Sengodan S. (2001), IP telephony with H.323: architectures for unified networks and integrated services, John Wiley & Sons

[5] Huang H. K. (1998), PACS: Basic Principles and Applications, Wiley-Liss

[6] The OpenH323 Project: http://www.openh323.org, [Last accessed 19/9/2005]

[7] ITU-T (1988), ITU-T Recommendation G.711, Pulse Code Modulation (PCM) of Voice Frequencies

[8] Gonzalez R. C., Woods R. E. (2002), *Digital Image Processing*, *Second Edition*, Prentice Hall

[9] Sidiropoulos K. P., Piliouras N. G., Athanasiadis E. I., Georgiou H. V., Makris C. S., Dimitropoulos N., Cavouras D. A. (2004), Statistical Versus Wavelet-Based despeckling techniques for enhancing medical ultrasound images, 1st International Conference “From Scientific Computing to Computational Engineering” (1st IC-SCCE)

[10] Banitsas K. A., Tachakra S., Istepanian R.S.H. (2002), Operational Parameters of a Medical Wireless LAN: Security, Range and Interference issues, IEEE EMBC 2002, pp. 1889-1890

[11] Khasnabish B. (2003), Implementing Voice over IP, John Wiley & Sons

[12] Gast M. (2002), 802.11 Wireless Networks-The Definitive Guide, O'Reilly

[13] Tanenbaum A. S. (1996), Computer Networks, Prentice Hall

[14] Sanders G. (2003), GPRS Networks, John Wiley & Sons

[15] Walke B., Seidenberg P., Althoff M. P. (2003), UMTS: The Fundamentals, John Wiley & Sons

[16] Khan J., Khwaja A., Khan J., Khwaja A. (2003), Building Secure Wireless Networks with 802.11, Wiley

[17] ITU-T (1998), ITU-T Recommendation H.245, Control Protocol for Multimedia Communication

[18] Rescorla E. (2000), SSL and TLS: Designing and Building Secure Systems, Addison-Wesley Professional

[19] Sadka A. (2002), Compressed Video Communications, John Wiley & Sons