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PDA-based system with teleradiology and image analysis capabilities

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***Abstract*—The aim of the present study was to design and implement a Personal Digital Assistant (PDA)-based teleradiology system incorporating image processing and analysis facilities for use in emergency situations within a hospital environment. The system comprised a DICOM-server, connected to an MRI unit, 3 wireless access points, and 3 PDAs (HP iPaq rx3715). PDA application software was developed in MS Embedded Visual C++ 4.0. Each PDA can receive, load, process and analyze hi-quality static MR images. Image processing includes gray-scale manipulation and spatial filtering techniques while image analysis incorporates a probabilistic neural network (PNN) classifier, which was optimally designed employing a suitable combination of textural features and was evaluated using the leave-one-out method. The PNN is capable of discriminating between three major types of human brain tumors with accuracy of 86.66%. The developed application may be useful as a mobile medical teleconsultation tool.**

I. Introduction

DURING the past few years the increased use of mobile devices, Personal Digital Assistants (PDAs), and wireless devices in general, has metamorphosed 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 [1, 2]. 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 the fixed position (clinical department), where traditionally medical diagnosis is performed.

The way for wireless transfer of patient images and information has been recently opened up by ongoing research projects that have proposed various, PDA-based, telemedical systems [3, 4] as tools to assist medical diagnosis within or without the hospital environment. The aforementioned developed systems, even though capable of providing mobility to the consultants, are limited to offer only access to patient's medical records (clinical data and information) [5]. The capabilities that such systems provide, regarding medical images, are basic image viewing and processing operations [6-8]. The need for more sophisticated image processing and analysis techniques that may provide additive information to the consultant is still an open issue.

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 processing and analysis of static high quality medical images. Moreover, the technological fusion of modern PDA handheld devices, wireless networking technology, and image processing and analysis techniques can provide the solution to modern medical teleconsultation within an all-wireless digital hospital environment.

The aim of the present study was to design and implement an integrated PDA-based teleconsultation system capable of providing image processing and analysis procedures to assist consultants. The proposed system is able a/ to receive, store locally, and load images from the DICOM server, b/ to process images using special-purpose algorithms to enhance image quality, and, finally, c/ to discriminate between three major categories of human brain tumors (metastasis, meningioma and glioma), employing Texture Analysis (TA) and Probabilistic Neural Networks (PNNs).

II. Materials and Methods

A. Hardware and software

The hardware platform chosen for the final prototype of this study 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 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 is the Windows Mobile 2003 SE.

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The DICOM-server was a Siemens SIENET MagicView 1000, featuring an UltraSparc1 processor, 448 MB of RAM and 18 GB of HDD storage with Sun Solaris operating environment. Medical images were stored in the server in DICOM format.

The software packages used for developing the PDA-based application were: a/ Microsoft Embedded Visual C++ 4 (High Level Software Development Environment and Compiler) and b/ Windows Mobile 2003 Software Development Kit (SDK) [9]. The application was developed on a typical desktop PC (Intel Pentium 4 @ 3 GHz with 1GB RAM) running Microsoft Windows XP.

B. System architecture

The architecture of the system (Fig. 1) consisted of three lightweight PDA devices that the consultants carried with them while roaming around the hospital and the DICOM server, which is connected to the hospital's MR modality (SIEMENS-Sonata 1.5 Tesla) through the DICOM 3.0 protocol. The PDA devices were connected to the DICOM-server using Wireless LAN (WLAN) technology through properly installed access points that covered a specific hospital area.

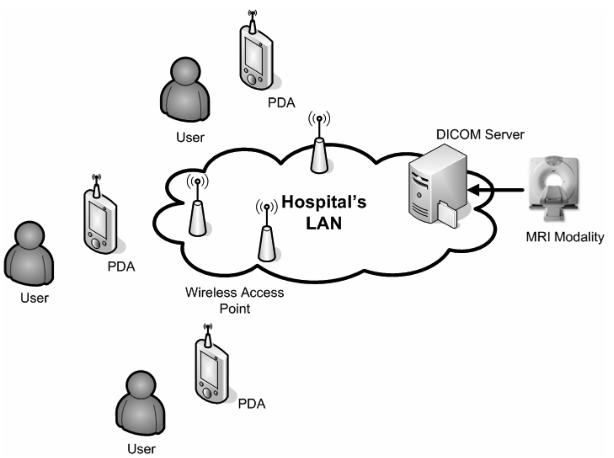

Fig. 1. System architecture.

C. Image retrieval and manipulation

Taking full advantage of the wireless networking card, the PDA application connects to the DICOM server database, downloads, and stores the images of interest on the PDA's storage card. In the present study, a 1GB storage card was used for providing the user with sufficient storage capacity, considering that the average image size utilized was about 600kB (512x512 grayscale DICOM image). The typical image transfer time was about 4 seconds.

The application 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 pixels can also be viewed using a special 'Shrink to Fit' function (Fig. 2a) 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.

D. Image processing

Image quality can be enhanced using standard image processing algorithms specific for medical applications, including the "windowing correction" technique that adjusts grayscale mapping for higher image contrast (Fig. 2b). In addition, the application employs more advanced image enhancement techniques for a/ contrast enhancement by means of the CDF histogram modification (Cumulative Density Function based Histogram Equalization) and b/ standard 2-D convolution filtering including median, smoothing, laplacian, high emphasis and unsharp masking [10]. Finally, the complete color map can be inverted, resulting in the corresponding negative image. Algorithms

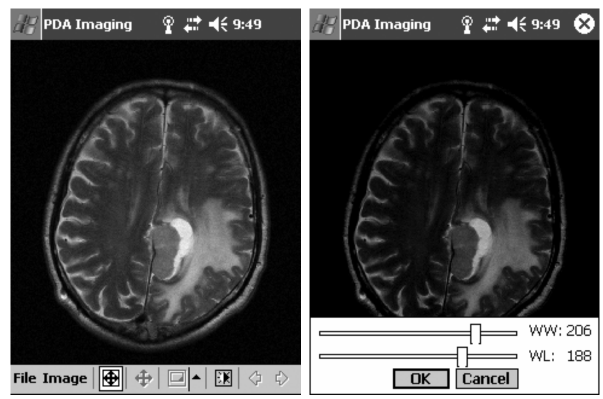

Fig. 2. a/ Image viewing with 'Shrink to Fit' function activated.
b/ Performing the windowing correction" technique.

were designed in a robust and compact way, in order to utilize the PDA's CPU and memory resources as optimally as possible.

E. System security

Medical data security was ensured by the employment of special remote access technologies, such as Wired Equivalent Privacy (WEP), Service Set Identifier (SSID) and Media Access Control (MAC) authentication [11]. To further enhance the security of the system, a pass code authentication at start-up of the application was implemented to prevent non authorized user access. For advanced security requirements, specialized data encryption protocols, such as Transport Layer Secure (TLS) can be integrated on the application to provide mutual authentication before any DICOM data exchange with the server. Furthermore, other models of PDAs can be used that have biometric security features integrated. These devices can be configured so that

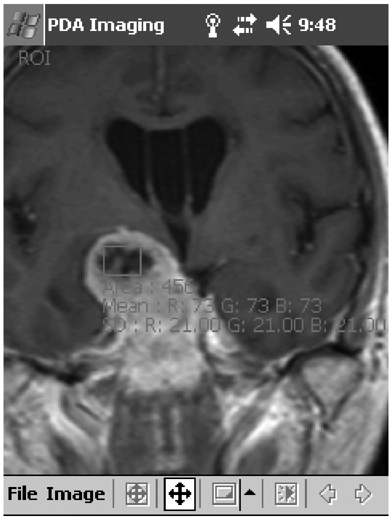

Fig. 3. Selecting a Region of Interest.

every time they become inactive for a length of time the user must go through a fingerprint security check. Only authorized fingerprints can access the information within the device.

F. Image analysis

The main contribution of the proposed system is the pattern recognition capabilities in discriminating between three types of brain tumors (metastasis, meningioma and glioma) by utilizing a PNN classification scheme.

The major bottleneck in designing and evaluating a PNN classifier is that training is a computational intensive process that involves many floating point calculations. Since the PDA devices have limited CPU capabilities, the PNN classifier was designed and evaluated on a typical desktop computer (Intel Pentium 4 @ 3 GHz with 1GB RAM).

Clinical material utilized for the training process comprised 25 subjects from the Hellenic Airforce Hospital with histologically confirmed intracranial tumors (8 metastasis, 7 meningiomas and 10 gliomas). From each subject, three (traversal, coronal and sagittal) T1-weighted post-contrast (Gadolinium) 512x512 grayscale DICOM images (approximately 600kB each) with Spin Echo (SE) sequence, Echo Time (TE=15ms) and Repetition Time (TR=500ms) were used, obtained by a SIEMENS-Sonata 1.5 Tesla MR Modality. Employing these images, the radiologist specified ROIs that included tumor regions. From each ROI, a series of features were extracted; 4 features from the ROI's histogram, 22 from the co-occurrence matrices [12], and 10 from the run-length matrices [13]. Extracted features (Table I) were used to design a PNN classifier.

The PNN is a non-parametric four-layer feed-forward neural network classifier. The PNN determines each class probability density function (PDF) by linearly combining the kernel PDF estimation for each training sample separately for a given class. Its discriminant function is given by [14]:

$$d_i(x) = \frac{1}{(2\pi)^{d/2}\sigma^d}\frac{1}{N}\sum_{k=1}^{N}\exp\left[-\frac{(x-x_{ik})^T(x-x_{ik})}{2\sigma^2}\right] \quad (1)$$

TABLE I
TEXTURAL FEATURES EXTRACTED

Methods	Calculated Parameters
Histogram (1st order statistics)	Mean Value, Standard Deviation, Skewness, Kurtosis
Mean and range of 0°, 45°, 90° and 135° co-occurrence matrices (2nd order statistics)	Angular Second Moment, Contrast, Correlation, Sum Of Squares, Inverse Difference Moment, Sum Average, Sum Variance, Sum Entropy, Entropy, Difference Variance, Difference Entropy
Mean and range of 0°, 45°, 90° and 135° run-length matrices (2nd order statistics)	Short Run Emphasis, Long Run Emphasis, Gray Level Non Uniformity, Run Length Non Uniformity, Run Percentage

where σ is the spread of the Gaussian activation function, N is the number of pattern vectors, d is the dimensionality of pattern vectors and x_{ik} is the kth pattern vector of class i.

Classification performance was evaluated employing the leave-one-out [15] method and for all possible combinations up to 3. The classifier was finally designed using the best features vector combination that resulted from the training process. All algorithms were implemented using custom software developed in C++.

Following training, the designed PNN model is exported to a single XML file that contains the optimal classification parameters, for distinguishing between tumor categories. Once the XML file is loaded onto the PDA, the user can retrieve from the DICOM server any series of T1-weighted post-contrast images and draw a ROI on any image containing the tumor area. According to the optimally designed PNN classification model, the PDA application may classify a ROI, drawn from an MRI image, to one of the three pre-defined tumor types (metastasis, meningioma, or glioma).

III. RESULTS AND DISCUSSION

A prototype of the system was tested and received positive remarks from physicians, as it allowed for easy teleconsultation. The clinical department, where the experiment took place, was covered with WIFI using three IEEE 802.11b compliant access points (APs), providing wireless access to any authorized client inside their cover range. APs were positioned 20 meters apart to ensure maximum cover range.

Static image viewing was evaluated as adequate by the expert physician (M.M), 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, etc.). Full DICOM transfer and decoding support on the PDAs, rendered the proposed system plausible for a modern hospital environment.

PNN classification scheme was optimized regarding

TABLE II
SYSTEM CONSISTENCY EVALUATION USING THE THREE BEST TEXTURAL FEATURES AND THE LEAVE-ONE-OUT TECHNIQUE

	Metastasis	Meningiomas	Gliomas	Accuracy
Metastasis	18	1	3	81.81%
Meningiomas	3	20	0	86.95%
Gliomas	3	0	27	90.00%
				86.66%

parameter settings and available feature data. The spread of Gaussian function was experimentally set equal to σ=0.3. Best feature vector, used for the optimal design of the PNN classifier, comprised the mean value of the ROI and two features from the co-occurrence matrix (entropy and difference entropy). The overall classification accuracy for discriminating the three types of human brain tumors was 86.66% (Table II). These findings are comparable to those found in previous studies in discriminating brain tumors on MRI, using either textural [16], spectroscopic [17, 18], or a combination of both textural and spectroscopic [19] features.

Regarding future work, the utilization of advanced algorithms to enhance tumor classification is under investigation. Support vector machines classifier along with feature transformation techniques, such as least squares mapping, will be employed to achieve higher discrimination accuracies between the types of brain tumors.

IV. CONCLUSION

Modern PDA handheld devices, combined with wireless networking technology and image processing and analysis 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 image processing and analysis services on PDAs. The system's features assisted physicians in applying state-of-art, rich media teleconsultation.

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