Development and evaluation of a PDA-based teleradiology terminal in thyroid nodule diagnosis

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Summary

We developed a wireless personal digital assistant (PDA)-based teleradiology terminal which allowed a secure connection to the hospital's Picture Archiving and Communication System (PACS) through the DICOM protocol. Ten members of the hospital's medical staff completed a questionnaire about its mobility, usability, stability, performance and diagnostic efficiency in a real health-care environment. There was a high degree of satisfaction with the system's mobility (mean score 4.1, SD 1.0, on a five-point scale), usability (mean score 4.2, SD 1.1), stability (mean score 3.9, SD 0.4) and performance (mean score 4.2, SD 0.6). The system was evaluated as a tool for providing assistance in diagnosing thyroid nodules from ultrasound images. A total of 144 ultrasound images with thyroid nodules were assessed by an expert. Six image quality attributes were evaluated. The physician concluded that the ultrasound thyroid images on the PDA screen were of similar quality to those displayed on a diagnostic visual display unit screen. However, the expert found difficulties in diagnosing microcalcification, internal echo texture and vascularity. The PDA terminal provided rapid, secure and convenient portable access to PACS images and the image quality was sufficient for diagnostic interpretation of ultrasound images of the thyroid.

Introduction

Over the last few years, several mobile teleradiology systems have been developed based on personal digital assistants (PDAs).[1–5] In a recent study,[6] a PDA phone-based emergency teleradiology system was designed to capture and share the PACS screen between a remote specialist and the emergency physician on duty via wireless links. In another study,[7] open-source software was installed on a Linux-based pocket-sized mobile DICOM server[8] to allow management of DICOM images through PDA or laptop PC clients via a wireless LAN. In an earlier study,[9] a DICOM-compliant, handheld image access system was developed in which a PDA server acted as the gateway to a PACS for PDAs. The system was capable of both wired and wireless transfer of images and included PDA and web interfaces that allowed various image manipulation functions. These studies found that use of PDAs could increase the efficiency of the radiology work flow, increase productivity and improve communication between referring physicians, remote experts and patients.

However, most of these systems[1–5,10,11] transcoded medical images into a non-DICOM format in order to display them with the PDA's built-in web browser, which consequently reduced the image quality. Even though expert physicians instantly and unconsciously identify the degradation in image quality,[12,13] they are unaware of precisely which diagnostic attributes are affected the most when examining images displayed on a PDA. Moreover, they are unaware of precisely how this may affect their diagnostic conclusions. Previous PDA studies have only focused on measuring user satisfaction in terms of mobility, usability, stability and performance.[1–5,10,11] However, to our knowledge there have been no previous studies to investigate the potential of PDAs as a tool for assisting in remote diagnosis using the DICOM format.

We have developed a wireless PDA-based teleradiology terminal and evaluated its feasibility and diagnostic accuracy in patients with thyroid nodules. Such a terminal might be valuable in allowing rapid remote first opinion diagnosis for case referral, emergency guidance in the absence of an expert physician and

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case conferences for more accurate diagnosis of thyroid nodules.

Prototype wireless PDA teleradiology terminal

The PDA chosen was the HP iPaq rx3715 which has a 240 × 320 pixel 16-bit colour TFT display. It has WiFi connectivity through an integrated IEEE 802.11b wireless network card as well as Bluetooth connectivity.

The application that was developed could connect to the hospital's Picture Archiving and Communication System (PACS) through wireless access points, query the server for patient studies, and download and store on the PDA's storage card the images of interest in DICOM format. The application could open almost any size of DICOM image, but the maximum visible resolution was limited to 240 × 240 pixels in portrait mode or 320 × 240 in landscape mode. Images larger than these resolutions could also be viewed using a 'Shrink to Fit' function, so that the original image fitted into a 240 × 240 or 320 × 240 frame (Figure 1). If the 'Shrink to Fit' function was not used, the user had the ability to scroll the image (using the stylus) at its original size. There was also the option to zoom as well as full screen viewing. The feature of rotating an image, in multiples of 90°, was also supported. In addition, standard mirroring and flipping image transformations were supported. Finally, the information contained in the DICOM header could be accessed to obtain information regarding the displayed image (Figure 2).

The application could process the loaded images using special-purpose algorithms to enhance image quality (Figure 3). One of the most commonly used image enhancement methods is the 'windowing correction' technique,[14] which was 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 used 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 filtering; and (c) adaptive median filtering for de-speckling of ultrasound images. Algorithms were designed in a robust and compact way, in order to comply with the PDA's CPU efficiency, and to reduce the processing time.

Figure 1 DICOM image displayed on the PDA screen

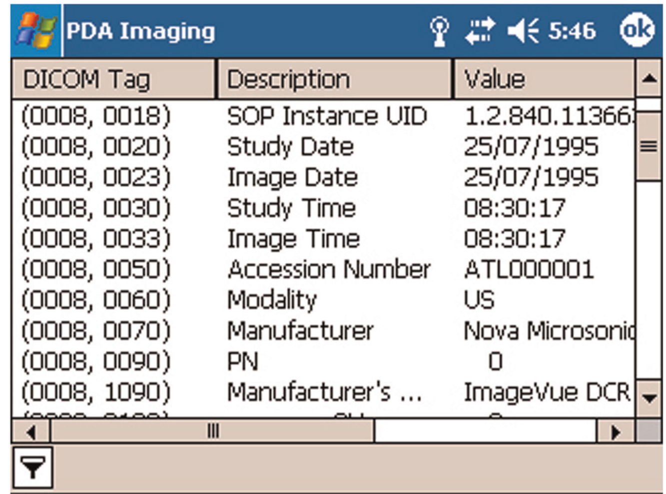

Figure 2 DICOM header information viewed on the PDA screen

Methods

We measured image transfer speed in a health-care environment (the Euromedica Medical Centre). Previous studies which have utilized PDAs for medical applications have demonstrated the efficacy of their systems in terms of mobility, usability, stability and performance.[1–5,10,11] We also tested our system in terms of mobility, usability, stability and performance. Mobility is a measure of how the user finds the carrying, storing and operation of the equipment. Usability refers to the capacity of the system to fulfil its purposes, i.e. downloading and uploading images and associated data. Stability refers to technical acceptability, i.e. any software malfunctions. Performance is an index of data processing time, i.e. the speed of loading images into the PDA. These four indices were evaluated using a questionnaire based on a five-point Likert scale. The tests were performed by ten users, who were expert physicians or resident physicians.

Diagnostic performance

The system was evaluated as a tool for providing assistance in diagnosing thyroid nodules from ultrasound images. The clinical material consisted of 144 ultrasound images (384 × 288 pixels at 8 bit resolution) from 72 patients with cytologically-confirmed thyroid nodules.[15,16] The grade of the nodules ranged from I to III. All ultrasound examinations were performed on an HDI-3000 ATL digital

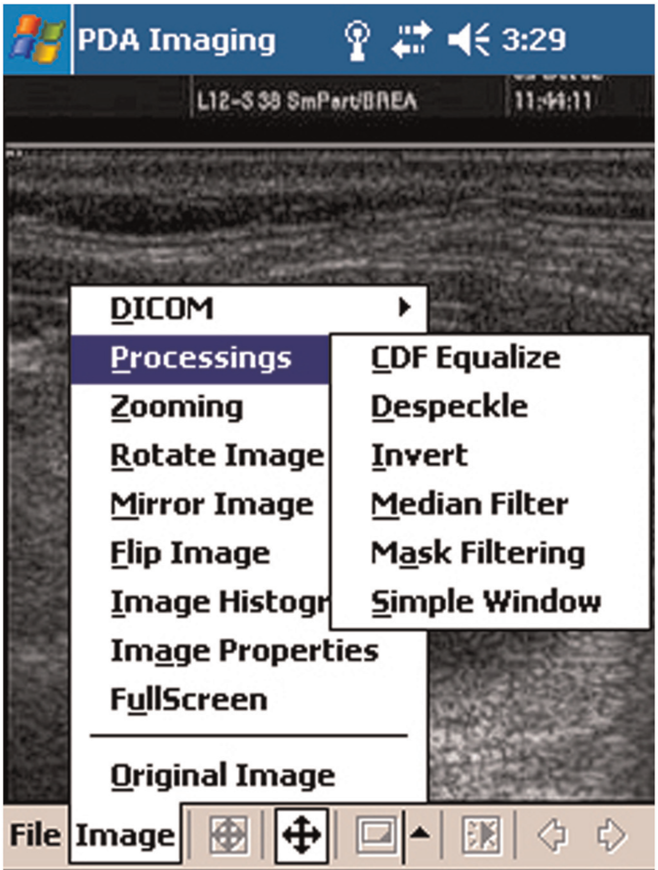

Figure 3 Special-purpose algorithms to enhance image quality

ultrasound system (Philips Ultrasound, Bothel, WA, USA) with a wideband (5–12 MHz) linear probe using longitudinal, transversal and sagittal cross sections of the thyroid gland.

The 144 ultrasound images were reviewed by an experienced physician. The image quality attributes that were evaluated were: the appearance of normal anatomical structures and surrounding tissues (F1), the nodules' boundaries and size (F2), the diagnostic quality and noise (appearance of speckle – granular patterns) (F3), the internal echo texture and appearance of microcalcifications (F4), the appearance of small structures (F5) and the tumour vascularity (F6). The physician was asked to assign a score from 1 (fail) to 10 (excellent) to each of these attributes. Scores below 5 were considered to represent cases where diagnosis was not possible. Scores 6–10 represented images whose quality was sufficient, fair, good, very good and excellent, respectively. Images were initially reviewed on the physician's visual display unit (VDU). After a period of one month, the images were resubmitted to the same physician for review on the PDA. After another two weeks, the images were sent back to the physician to be evaluated on the PDA again, to assess intra-observer agreement.

The PDA's suitability as a remote diagnostic tool was assessed by comparing the imaging scores from the VDU and the PDA screen. After specifying the importance of each imaging attribute on the decision-making process using a decision tree structure,[17] the impact of degraded imaging attributes on the diagnostic conclusion was assessed.

Results

Transfer times from the PACS server to the PDA terminal were proportional to the image size, e.g. with a 3 Mbit/s wireless connection, a 500 kByte image took less than 4 s to download. The questionnaire survey of the 10 medical professionals showed a high degree of satisfaction with the system's mobility (mean score 4.1, SD 1.0), usability (mean score 4.2, SD 1.1), stability (mean score 3.9, SD 0.4) and performance (mean score 4.2, SD 0.6).

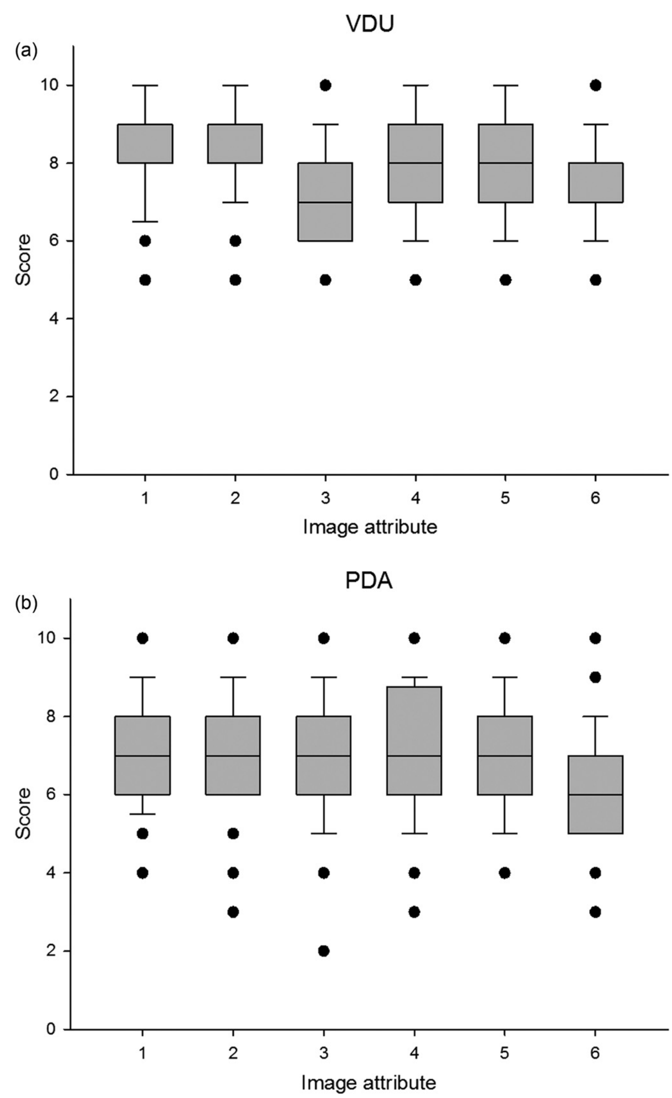

Figure 4 Box plots for each imaging attribute assessed by the experienced physician. The boundary of the box closest to zero indicates the 25th percentile, the line inside the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. The whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. (a) scores for the VDU screen; (b) scores for the PDA screen

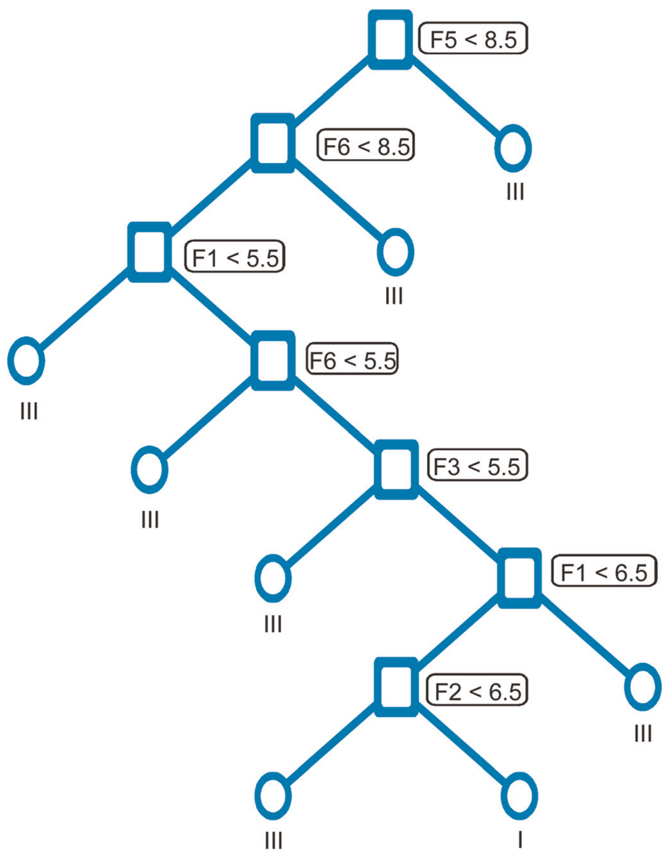

Figure 5 Decision tree for identifying the most important features taken into account during the diagnostic process

The box plots for each imaging attribute are shown in Figure 4. The image attributes were not significantly different between the two screens.

The importance of each imaging attribute on the decision making process is summarised in Figure 5. The question is the ease of discriminating grade I from grade III nodules with respect to image quality. For example, the first node indicates that if small structures (imaging attribute F5) are displayed with very good quality (i.e. F5 $>$ 8.5), then the physician may easily discriminate grade III nodules. If F5 $\leq$ 8.5 then the physician may conveniently visualize grade III nodules when F6 (tumour vascularity) is displayed with very good quality (i.e. F6 $>$ 8.5). The one variable found to affect the visualization of grade I nodules is the appearance of speckle and granular patterns (F2). For fair quality of F2 (i.e. F2 $<$ 6.5) grade I nodules can be easily discriminated.

The physician's intra-observer agreement was found to be very good for each imaging attribute (see Table 1). The average percentage of images with respect to image quality category to which these were classified is shown in Table 2.

Table 1 Intra-observer agreement on the six imaging attributes viewed on the PDA. Values shown are the percentage agreement ($n = 144$)

	F1	F2	F3	F4	F5	F6
Agreement (%)	93	96	93	91	96	95

Table 2 Mean scores for the imaging attributes. The values are the cumulative percentage of images ($n = 144$) in each category (%). Scores below 5 were considered to represent images that were impossible to diagnose

	>4	>5	>6	>7	>8	>9
PDA	100	95	66	49	21	6
VDU	100	100	95	73	49	19

Table 3 Scores for each imaging attribute on the VDU and PDA screens. The values are the mean scores (SD)

Imaging attribute	VDU	PDA screen	Difference in mean values (%)
F1	8.3 (1.3)	7.3 (1.4)	14
F2	8.3 (1.4)	7.3 (15)	14
F3	8.0 (1.3)	6.6 (1.3)	21
F4	8.1 (1.4)	6.8 (1.4)	19
F5	8.3 (1.2)	7.2 (1.3)	16
F6	8.3 (1.4)	6.9 (1.3)	20

The mean scoring values for each imaging attribute on the VDU and PDA screen are shown in Table 3.

Discussion

The PDA terminal received very positive comments from the users as it allowed easier, more reliable and faster teleconsultation when tested in a real health-care environment. Full DICOM transfer and decoding support for image files made the application useful in a modern hospital environment. Most of the algorithms exhibited acceptable performance regarding their processing times. For 384 $\times$ 288 thyroid ultrasound images, the processing times ranged from 1 s (windowing) to 5 s (de-speckling).

Image transfer times were found to be proportional to the image size, but also dependent on the network congestion and speed.

As far as the diagnostic capability of the PDA terminal was concerned, the physician concluded that the ultrasound thyroid images were of equal or better quality than when the images were displayed on the VDU. However, only 5% of the cases tested on the PDA screen fell below the not-possible-to-diagnose score, i.e. below 5. This indicates that the PDA provided image quality sufficient for diagnostic interpretation.

The results of the questionnaire provided useful information about image degradation on the PDA. Most of the cases presented sufficient quality for diagnostic purposes (95%). About half of the images were recognized as having good quality (49%). There were even some cases of very good quality (21%). The latter images were those having well established nodules, whose boundaries and extent were clearly visible. On the other hand, the expert had difficulty in diagnosing cases where microcalcifications, internal echo texture and vascularity were prominent.

The most significant degradation was found to be the appearance of internal echo texture and microcalcifications,[18] which is a feature closely associated with malignant thyroid nodules. The second most degraded imaging attribute concerned tumour vascularity, the prominence of which suggests increased metabolic activity of possibly malignant formations.[19] These two important features were degraded by about 20% on the PDA screen (see Table 3). On the other hand, the least significant degradation was found in the evaluation of the nodules' boundaries and size,[20] which provides clues about the location and extent of suspected lesions. Thus, although fine texture structures, such as microcalcifications and networks of small vessels, were severely degraded on the PDA screen, a gross estimation of the location of suspected lesions and borders was still feasible.

The uncertainty in score assignment was higher for the PDA cases (Figure 4), indicating that there was more variation when the physician assigned scores using the PDA screen, i.e. the observer became more uncertain. On the other hand, the median values were 1 or 2 points lower for each imaging attribute. The latter can be interpreted as follows: the expert physician became uncertain (i.e. the interquartile range increased) when making diagnoses on the PDA, but he did not become prohibitively confused.

After quantifying the extent of image degradation, a decision tree was constructed in order to 'rank' the estimated imaging attributes according to their impact in the diagnostic conclusion using the results obtained on the VDU as the gold standard. The decision tree indicates that the most important characteristic that defines the expert's outcome is the appearance of small structures (F5) followed by tumour vascularity (F6) and appearance of normal and surrounding tissues (F1). The degradation on F5 and F1 values was 1 point on average lower, whereas for F6, it was 2 points less. The latter reinforces the belief that a PDA-based teleradiology system might be used as a potential remote diagnostic assessment tool. Scenarios in which such systems might be utilized include:

(1) A non-expert physician performs a diagnosis on a VDU. However, he or she needs an immediate second opinion by an expert physician who is not located in the same facility. He or she can send the image directly to the PDA of an expert physician who will confirm or question the diagnosis;
(2) An endocrinologist palpates the thyroid gland of a patient and sends the patient for a thyroid examination. Without having to attend the examination, he or she may receive the acquired images and request for a re-examination if needed, and/or obtain an initial, rapid first opinion on the case.

In conclusion, the wireless PDA terminal provided fast, easy secure and convenient portable access to PACS images. The application supported browsing, searching and downloading of images in DICOM format, with average response times of less than 4 s. In addition, the response time for browsing/searching was usually less than 3 s. The PDA terminal was found to provide image quality sufficient for diagnostic interpretation for thyroid ultrasound images and potentially for ultrasound images, in general, of similar resolution ($384 \times 288 \times 8$ bit).

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