Image Processing Strategies in Picture Archiving and Communication Systems

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An image processing strategy is presented that assures very similar soft-copy presentation on diagnostic workstations of a picture archiving and communication system (PACS) over the lifetime of an image file and simultaneously provides efficient work-flow. The strategy is based on rigid partitioning of image processing into application- and display-device-specific processing. Application-specific processing is optimized for a reference display system. A description of this system is attached to the file header of the application-specifically processed image which is stored in the PACS. Every diagnostic display system automatically reproduces the image quality for which the application-specific processing was optimized by adjusting its properties by display-system-specific processing so that the system becomes effectively equal to the reference display system.

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IMAGE PRESENTATION in film-based digital radiology, illustrated in Fig 1, appears to have two distinct advantages over filmless radiology within an open picture archiving and communication system (PACS): (1) Typically, an image acquisition modality is connected in point-to-point fashion to a laser image printer. Application-specific processing and printer-internal processing are matched to yield expected image quality in the printed image; (2) The printed film image has archival properties so that the image quality that was used for finding the primary diagnosis is saved for the life of the image.

In today's filmless PAC systems, soft-copy display devices with different image quality are used for the primary diagnosis. Modality and application-specific image processing are typically not tuned to a given display device and presentation arrangement. Apart from the gray-scale response of the display system which may follow the digital imaging and communications in medicine (DICOM) Display Function Standard, image quality in the displayed image is not predictable. The display system may contain monochrome or color CRT monitors. The systems may be able to display 1280×1024 or 2560×2048 pixels. The displays may vary in the maximally producible luminance and luminance range and, especially, in the modula-

tion transfer function (MTF). Depending on the quality of the display, the radiologist may have to make extensive use of image processing tools such as contrast and brightness adjustments and edge enhancement as well as roaming and zooming to arrive at a diagnosis. These operations may require an appreciable length of time and affect the efficiency of the radiologist.

If the image is recalled from the archive in the future, the display system used in the past for the primary diagnosis may no longer exist. Display technology may have changed. The radiologist may not remember the display processes that he used for finding the primary diagnosis. In what follows, a processing strategy is outlined that overcomes these shortcomings.¹

IMAGE PROCESSING STAGES IN A PACS AND THE REFERENCE DISPLAY SYSTEM

In PAC systems, image processing should be systematically partitioned into four stages (Fig 2). Digital projection radiography such as stimulable phosphor computed radiography (CR) or flat-plate detector direct digital radiography will be used to illustrate these stages.

Sensor-Specific Processing

All sensor-related correction operations take place in the first stage. They may consist of correction for gain variations among different elements of the detector, correction for defective pixels, subtraction of systematic noise components, and elimination of distortion. The correction operations may also include MTF restorations to compensate degradations in resolution induced by the read mechanism. The resultant digital "raw" data typically cover the entire detector acquisition range which is wider than the clinically interesting data span. The clinically interesting data span depends on exposure level and technique factors as well as

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Fig 1. Image processing for digital radiography with film output.

on the imaged body part and reason for the examination.

Application-Specific Processing

Application-specific processing may begin with an auto-ranging operation by which the clinically interesting data span is selected from the raw data range. (This is almost standard practice in stimule-phosphor and other CR systems.) Next, the image is spatially filtered to adjust the contrast of small and mid-size details and suppress random noise depending on the application requirements for presentation on a specific display system called the reference display system (see next Section).

The filtered image is still represented by the full digitization resolution (eg, 10 or 15 bits). The file header of the image contains a table defining the difference between the desired gray-scale rendition and the DICOM Display Function that all display systems are required to reproduce.

Our processing strategy assumes that PACS workstations, even diagnostic workstations, do not have the capability to perform the myriad of different modality and application-specific processing operations (for CR, CT, MRI, US, and so on)

except for gray-scale mapping and a tool set of general-purpose processing functions. By not reducing the digitization resolution at the end of the modality and application-specific image processing and by attaching the desired gray-scale rendering function to the image file, greatest flexibility for the image user is maintained to adjust gray-scale presentation. Moreover, the modality and application-specific image processing may be chosen such that, after some gray-scale transformation, the processing state is also suitable for hard-copy printing. To implement this transformation, it is desirable that the image is still presented with high digitization resolution.

Reference Display System

The modality and application-specific processing should yield image quality such that, for finding the primary diagnosis, a minimum of user interactions, if any at all, are required on the reference display system. A goal for the reference display system may be that all clinically interesting anatomical and pathological details can be rendered in a single presentation setting as on a hard-copy film when hung in front of a light-box.

Fig 2. Image processing for the primary image interpretation on workstations of a PACS.

The reference display system is characterized by the following nine parameter sets: (1) Type of display (eg, monochrome CRT with P45 phosphor or color liquid-crystal display (LCD)); (2) Nominal pixel size and pixel matrix (eg, 170 μ m, 1726 $\times$ 2304); (3) Display controller output look-up table (eg, 8-bit in/10-bit out); (4) Display system follows DICOM Display Function Standard; (5) Maximum luminance and luminance range; (6) MTF (typically 8 representative data pairs); (7) Multi-format arrangement (eg, 12 on 1); (8) Expected pixel mapping (eg, one-on-one or one-on-two-by-two); and (9) Interpolation technique (eg, high-resolution cubic spline). The reference display system parameters are made part of the image file header. They describe the display system for which the modality and application-specific processing parameters were optimized. Together with modality- or application-specific gray-scale transformations and user-initiated processing operations, which are executed at the time of viewing the radiograph, they define the image presentation state that the radiologist used for the primary interpretation.

Display-System-Specific Image Processing

The properties of the display system (the display controller and, for example, a monochrome CRT monitor) must be known and monitored. By comparing the measured maximum luminance, luminance range, image size, MTF, and noise with the reference display system characteristics, image processing operations may be derived that make the displayed image quality equivalent to that expected from the reference display system. For the execution of these processing operations, the modality image data should have high digitization resolution.

Obviously, the reference display system properties cannot differ too strongly from the actual properties of the display systems in the diagnostic workstations at hand. Otherwise, it may be impossible to implement the reference display. The reference display system properties and the modality and application-specific image processing state should be appropriately chosen for the display technology and image processing power of the diagnostic workstations.

Today's high-resolution display systems (with 4 or 5 million addressable pixels) do not provide image quality that, without user interaction with the display system, is clinically equivalent to a film

print. Typically, the maximum luminance is lower by a factor of five to ten. The luminance range may be smaller. The MTF is anisotropic and may have, at the Nyquist frequency, a value of 0.5 in vertical direction and of 0.2 in horizontal direction. A typical laser image printer has a uniform modulation transfer factor of 0.8 at the Nyquist frequency of the printed image. Finally, the soft-copy display system may have higher noise.

As has been shown,^{2,3} it is entirely possible to compensate such differences in display system performance by image processing. When using the image state of digital chest radiographs that the modality processor (of a dedicated thorax imaging system with a selenium detector) prepared for a laser image recorder, the soft-copy-specific processing included standard tone-scale reproduction, compensation of psycho-physical effects owing to lower luminance, luminance range, and image size, and anisotropic MTF restoration. For a single display setting and without user interaction, the resultant soft-copy image on a 4-million-pixel CRT display system was found to be clinically and visually equivalent to the hard-copy film hung in front of a light-box.

Modality- or Application-Initiated and User-Interactive Presentation Processing

The last stage of the image processing chain may consist of two sets of operations: First, the modality- or application-specific gray-scale rendition, which is presented as a table in the image file header, is implemented. This operation is best combined with the standard tone-scale reproduction of the display-system-specific processing and is preferably executed with high digitization resolution. Second, the user may interactively change the gray-scale rendition, for example, by adjusting window-width and window level of the image that emerges from the first operation, and sharpen the image. Additionally, the user may employ zooming and roaming in the course of the primary interpretation of the image.

The first operation really is part of the application-specific processing. It is implemented at this late stage to permit the user to choose an entirely different gray-scale rendition. However, instead of applying gray-scale operations in succession, the application-specific gray-scale rendition may be discarded and the user-preferred rendition may be applied in its place. This technique is especially

preferable when, for whatever reason, the digitization resolution of the image data had been reduced at a preceding stage.

The user-applied functions shall be recorded in the image file header so that the image presentation that was used for the primary diagnosis is automatically reproduced as the default state concerning the gray-scale rendition, edge-enhancement, and zooming when the image is recalled and that, for example, by a flashing text overlay—"roam!"—it is indicated to a later user how the image was viewed originally.

DISCUSSION

By defining and effectively realizing a reference display system, several objectives are accomplished: (1) The soft-copy image quality becomes essentially independent of the display technology of a given diagnostic workstation; (2) Workstations automatically fulfill presentation expectations of the user; (3) The image quality is very similar at all diagnostic workstations in which the reference display conditions have been implemented; (4) If the reference display system provides sufficiently high image quality, user interactions may not be required for routine application; (5) Because the properties of the reference display system are part of the image header and because the application-specific image processing state provided by the modality is archived—not the processing state produced for a specific display system, the image can be displayed with the same image quality at any diagnostic workstation in the future.

The concept of our reference display system has some similarity with the embedded profiles of the Apple ColorSync principle (Apple Corp, Cupertino, CA).

The reference display system does not represent a standard. It may be adapted to specific applications, display technologies, and available system processing capabilities. It may be changed at any time. Nevertheless, the definition of the reference display system is a non-trivial task. Not only has it an impact on PACS architecture and performance, but also, as pointed out earlier, on the efficiency of the radiologists.

Two of the most crucial considerations are (1) For a given actual display system, are there algorithms and implementations available to realize the reference display system without significantly affecting the work-flow? (2) What is the best division

of image processing between modality or application-specific processing and display-system-specific processing?

Conceivably, most of the display-system-specific processing, especially the time-consuming anisotropic spatial filtering for the MTF restoration of the display system, could be executed by the modality image processor. The relatively short delay owing to the spatial filtering then does not matter. This strategy, however, may have two disadvantages: (1) The image prepared by the modality processor is no longer suitable for printing unless the printer or print server could reverse the MTF restoration; (2) An image is archived that is processed too much for the intrinsic properties of a specific display system. Similar to the printer situation, future display systems would have to have the capability of reversing some of the processing operations implemented earlier. Correspondingly, it may be disadvantageous to send an image that was specifically processed for a given diagnostic workstation technology to a lower-resolution clinical review stations or personal computer on the physician's desk. Thus, the image prepared by the modality or application processor should be as universally useful as possible. Every presentation device should process the image according to the specification of the reference display system and its own intrinsic properties.

Patient or examination folders are often downloaded to a given workstation at the instance a user needs them. Any requested image must be displayed within a few seconds after issuing the request. Presently, the MTF restoration operation lasts about one and a half minutes on a relatively slow computer (SUN SPARC 20 with 75-MHz processor and a 256-MB RAM). Two scenarios are conceivable to execute the time-consuming display-specific processing in advance: (1) The patient folders are pre-loaded to the workstations for display-device-specific image processing; (2) The active file server may automatically create image files with the MTF restoration which are transferred to specific workstations on demand. This strategy would be based on our experience that only small differences in MTF exist between monitors of a given model. Hence, the MTF restoration can be performed in advance for all diagnostic workstations with the same type of CRT monitor. The disadvantage of this scenario is that the active file storage system must hold two versions of every

image: (a) the one prepared by the application processor and (b) the MTF-restored one. The first image version is to be archived after the primary diagnosis is completed and after the image file has been tagged with the user-initiated processing operations.

CONCLUSION

An image processing strategy has been presented by which radiological images can be displayed with high image quality so that little, if any, user interaction is required. By tagging the image file with a description of the reference display system

that was used for the primary diagnosis, the same image quality may be maintained over the lifetime of the image file.

Existing and proposed DICOM standards like the supplements for digital radiography and for the soft-copy presentation state address only limited aspects of our strategy. It is proposed that the DICOM Committee considers providing a standard protocol for our entire tagging concept.

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REFERENCES

1. Blume H, Bergström S, Goble J: Image pre-hanging and processing strategies for efficient work-flow management with diagnostic radiology workstations. *J Digit Imaging* 11:66, 1998 (suppl 1)
2. Reiker GG, Blume H, Slone RM, et al: Filmless digital

chest radiography within the radiology department. *Proc SPIE* 3035:355-368, 1997

3. Blume H: Image processing and presentation strategies in PACS. infoRAD Theater Presentation, RSNA 83rd Scientific Assembly and Annual Meeting, Chicago, IL, Nov. 30 to Dec. 5, 1997.