A Client Server Model to Facilitate Creation of a Medical Image Teaching Library

William J. Hornof, Dennis W. Ballance, Paul R. Brenston, and James A. Self

A simple and convenient system for indexing and archiving medical images used in teaching was developed. The approach was to combine a smart client-side graphical user interface that controlled image size, file format, and keyword structure, and communicated with the hospital information system via hyper-text markup language, to populate the interface with user selectable pull-down menus. The result is a system that is easily extensible beyond the radiology images for which it was originally designed. Only minor modifications of the client interface are required to adapt the program to accept any file format or image type.

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MODERN DIGITAL SCANNERS and cameras are capable of capturing all image information contained in a radiograph, microscope slide, or 35-mm slide. Once digitized, a film recorder can be used to print these images on film for slides, or on x-ray film for high-quality, full-size radiographic copies. They also may be incorporated directly into computer-based teaching modules. However, these digital image files are no more readily retrieved and accessed than a stack of slides, unless each is indexed and categorized.¹⁻³ Most digital image formats contain a header, which can contain textual information. If structured key words could be entered in the header file of the image, the location of the image could be tracked by computer, and copies could be made without fear of loss or damage to the original. Unfortunately, creating and maintaining a searchable digital library is not accomplished without consuming considerable resources, and it requires no less effort to index and categorize a "stack" of digital images than it does a stack of slides.

We theorized that, if a convenient system could be established, clinical faculty and house officers

would take the time to enter key words when producing instructional materials, in order to retrieve appropriate cases/images at a later date. This report describes our efforts to devise such a system for archiving and indexing radiographic images for teaching, while maintaining the extensibility of the system to other image types.

SYSTEM DESIGN AND OPERATION

The decision was made that the image archive would need to be centrally managed to ensure system reliability and security, and to protect intellectual property rights. However, to be convenient, the system also would need to support image input from multiple and potentially remote sites. The availability and reliability of the existing Hospital Information System (HIS), developed in-house at the Veterinary Medical Teaching Hospital (VMTH), formed the backbone of this effort.

We initially defined desirable features of such a system. These include:

1. The fact that images were being archived should be as transparent to the user as possible.
2. The system should not require specific actions of individual users to make things work properly (eg, saving or naming files).
3. The system should support multiple input sites.
4. The system should impart structure to the key-word entry, but to be readily accepted the key-word entry process would need to be as flexible as possible.
5. The system should control image quality and file format.
6. The system should prevent having multiple copies of the same radiograph archived.
7. The system should ensure that the file name of each image is unique, regardless of where and when it was entered.
8. Portions of the system should be exportable to other institutions in the hope of starting an interinstitutional shared library.
9. The system should protect the storage capacity and bandwidth of the HIS from becoming overwhelmed and thus adversely affecting operations.

From the School of Veterinary Medicine, Veterinary Medical Teaching Hospital, University of California, Davis, CA.

Address reprint requests to William J. Hornof, DVM, MS, Department of Surgical and Radiological Sciences, School of Veterinary Medicine, University of California, Davis, CA 95616.

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Information relating the image to a specific patient (such as age, species, and sex) already were stored in the HIS and indexed by a unique case number. The HIS already was capable of providing an HTML representation of the patient record, and supported a common gateway interface that returned all patient demographic information along with a list of all procedures performed and their dates, in response to any specific case number (Fig 1). Thus, communication with the HIS at the time of image capture was used to speed the indexing process. In addition to the index terms relating the image to the patient, the HIS also contained valuable indexing information relative to the type of studies conducted on that patient (eg, thoracic v abdominal radiographic examination).

An existing application⁴ for scanning radiographs, again developed in-house, was modified by devising a scheme for this application to initiate HTML communication with the HIS (Fig 2). This new client-side application first required the user to input a valid VMTH user name and password, and

to enter the VMTH patient number of the case about to be scanned. Using that patient number, the application then queries the common gateway interface. (The user also can select "Non-VMTH," in which case the HIS is not queried.) In response, the HIS provides access to this URL, and returns an HTML file containing age, species, sex, a list of all procedures conducted along with their dates, and a list of all previously digitized images associated with that patient. The client application parses this information and inserts the procedure information into the user interface, permitting the user to select the specific imaging study being input. It was decided to permit free text entry for a diagnosis field. This decision was made because the clinical diagnosis may not have been defined in the HIS at the time of image capture, or may not be related to why the radiograph was being digitized. It also was decided that the diagnosis alone often is of less importance to a clinical instructor than the "pattern" demonstrated by an image associated with a particular case. Two addi-

Fig 1. Schematic drawing of communications between the hospital information system (server side) and a local computer (client side) used for image input. All communications are via HTML. The end result is generation of two identical copies of the image file, one locally for immediate use and one on the server for permanent archiving. Both files contain all indexing and retrieval information in the header file.

Fig 2. Screen capture of the user interface acquired immediately after image capture. The sources of the information are shown. (A) User entries to log on and identify patient. (B) Number of images in archive for this patient. (C) Pull-down menu populated by server, with all imaging modalities performed on this patient. (D) Patient information populated by server. (E) Pull-down menu populated by server, with all procedures performed on this patient in selected imaging modality. (F) Free text user entries. (G) Manual control of scanner and file format (images not archived).

tional free text fields for "findings" also were added.

Once the user is satisfied with the key-word entry, the client application then activates a Lumisys 75 (Lumisys Inc, Sunnyvale, CA) radiograph scanner to create a 12-bit image of approximately $2,048 \times 2,500$ pixels for large films ($14" \times 17"$), or at the maximum resolution of the scanner ($100\text{-}\mu\text{m}$ spot size) for smaller film sizes. An automated 12- to 8-bit conversion algorithm was applied⁴ and a 128×128 thumbnail displayed by the application to allow the user to change the final orientation of the image. Once the user is satisfied with the image orientation, the HIS generates a unique file name by combining the case number, procedure code, date of procedure, and an incremental counter. (The user also can select a "manual" mode and be provided complete control of the scanner and output file type, but no key words or thumbnails are created, and these files are not named or archived.) All information, including the user's name and institution's name, is inserted automatically into the image header file, using Adobe Photoshop keyword format (Adobe Systems Inc, San Jose, CA). A three- to four-character identifier, unique to that

field, precedes each key word. For example, the age of the patient is preceded by "age=," and species is preceded by "spc=." Thus, the content of each key-word field is uniquely identified. The image is then stored as a high-quality JPEG file on the user's machine. In addition, the interface program posts all key-word information, the JPEG file, and two JPEG compressed thumbnails (64×64 and 256×256) to the HIS, using HTML, and deposits it on the VMTH image server.

Upon receipt of the information, the HIS automatically creates indexes and links between the images and the computerized patient record. The 64×64 thumbnail is linked to both the textual report from which the image originated (eg, radiographic report) and the full-resolution image. When the report is displayed with a web browser, this thumbnail is a hot-link to the full-resolution image. The 256×256 thumbnails are indexed separately to the posted key words and linked to the full-resolution images to facilitate searching and selecting images in the HIS image library. Thumbnails and full-resolution images can be viewed directly in a browser window.

These thumbnails also are used at the time of

image capture to inform users of potential duplication. If the user selects a study (eg, thoracic radiograph obtained on a specific date) for which images in the HIS image library already have been indexed, thumbnails of those images are returned to the user interface. The user is then informed that the displayed thumbnails already exist in the library, and the user is given the choice of downloading the full-resolution versions or digitizing additional images from that study.

ADDITIONAL INTERFACES

Only minor modifications to the user interface were required to adapt it to accept input from a video capture card. Thus, images from endoscopy, arthroscopy, and ultrasonography could be indexed, archived, and linked to the textual report for those services, using the same system. As we began to expand image-input devices, it became clear that we could not afford to write interfaces for every possible image-input device. Instead we elected to write an interface that would open any stored TIFF or JPEG file. The interface then could be used to link any previously digitized image to a report for that service, or in the case of a photograph of a lesion, to the physical findings in the HIS's electronic medical record.

USER ACCEPTANCE

Concerned about overwhelming the storage and bandwidth of the HIS, the interface was installed on only three machines, in radiology-controlled areas: two for radiograph digitization and one for ultrasound video capture. The user interface was well accepted, and users digitized and indexed more than 4,000 radiographs in the first year of operation. Part of this success was attributable to the perceived desirability of being able to insert key words into the header at the time of image capture. Many users chose to archive their own copy of each scanned image, and created their own image library. Commercially available software could then be used to index and retrieve these cases in a personal library. We have found this tendency to be particularly true for residents desiring to establish large teaching files. An added benefit of entering an image into the system is that the textual report is automatically linked to the image, and vice versa.

Some individuals new to the system quickly discovered that simply selecting "Non-VMTH" saved time because prompts for key-word selection

and entry were avoided. This was particularly problematic when the system was new, and very few people understood what the system was doing. Initially, there was a perception that the indexing was only of value to the VMTH—not to the individual in immediate need of the image being scanned. However, once it was understood that the key-word information actually was inserted into the image header, and that individuals could create their own searchable library, compliance was attained easily. Now that there are significant numbers of knowledgeable users, and the value of indexing is well understood, there is little need to police the system. With the exception of regular purging of the hard drives on the three client machines, the need for ongoing user support and training in the use of the client interface also has been minimal. However, the ready availability of high-quality digital images has spawned an increased demand for training and support in image manipulation and presentation software.

DISCUSSION

Obtaining and maintaining quality sets of images to demonstrate normal and disease states for teaching purposes is a continual challenge facing academic clinicians in most specialty areas. Most clinical instructors gradually accumulate vast slide sets from cases encountered during their careers. Upon retirement, even though these slide sets may be turned over to replacement junior faculty, unless they are complete, well labeled, and indexed, they are essentially useless. Even if they have been carefully indexed and labeled, unless they are carefully guarded, many images will become damaged, lost, misplaced, or misfiled, thus rendering the collection useless. If the slide can be located, in many instances the original material (radiograph, microscope slide, etc) from which these slides were made, has been either lost or discarded, and usually there is no way to confirm or corroborate whatever cryptic notes were written on the slide. By providing a convenient system to link teaching images to the electronic medical record or other indexing schemes,¹⁻³ the potential exists to minimize this problem in the future.

Although radiographs from cases seen before the advent of the electronic medical record have been entered in our library, there has been no systematic attempt to retroactively catalogue collections. It was our belief that younger faculty and residents

without vast slide collections would be sufficiently motivated to make entries into the library. Although our initial concerns about individuals circumventing the indexing process were realized, this has proven to not be a problem. We also were concerned that individuals would refuse to index "their" cases because others might gain access. Now that the radiographic library has grown to critical mass (mainly driven by residents in Radiology and other services preparing for presentations and lectures), the value is clear. When a senior faculty member can find multiple quality examples of a rare disease, the value of an individual's "prize case" from 5 years ago is diminished.

The JPEG file format was chosen because it was browser-compliant, the code for the compression was in the public domain, and the format was supported by most image archive and image display applications, including browsers. JPEG also provided perceptually lossless compression, with greater than 10-fold reduction in file size of both gray scale⁴ and color images.

We believe the heavy client design of the system provides unique flexibility. For example, the system currently is not DICOM-compliant and uses exclusively HTTP communication protocols. Our HIS does not currently support DICOM communications, but if it did, the user interface could easily be modified to capitalize on that feature. The design of the system provides considerable control and flexibility in terms of system management without the need to provide supplemental end-user training. Regardless of modifications to the communication, transfer, and archiving protocols, if the user is still supplied a local copy of the file in JPEG format, those modifications would be totally transparent. Control of the client-side interface also provides the potential for each specialty area to individually define standards for image quality and file type. Further, since the HIS populates the fields in the user interface, individual services can define different or additional categories for indexing. In this model, the user interacts solely with the client application while the HIS provides that application with the necessary information to populate the windows and pull-down menus the user sees. No attempt was made to coerce users into complying with standards, but again the system design is such that current free text fields could be supplied interactively with a more structured vocabulary.

Of critical importance to the success of this

endeavor was the robust nature of the existing HIS, and its ability to provide an HTML version of the electronic medical record via the Worldwide Web. With that in place, it was merely a matter of modifying the client-side software to communicate and exchange information using established web protocols. A server side common gateway interface to search for key words, and generate a list of links to images containing those key words, has been written. Presently, the retrieval capabilities of the system support identifying individual key words, or sets of key words, but do not permit searching individual fields. We have not yet capitalized on the feature that a unique three- to four-character identifier precedes each key-word field. However, it should be relatively straightforward to create a server-generated HTML form that looks very much like the input interface, which would enable users to search individual fields for words or ranges of values. In addition, if things such as metadata standards are adopted nationally for indexing and identifying teaching materials, it should be relatively straightforward to write software that automatically maps existing key-word fields to those fields and key-word formats. Transparent modifications also could be made to the interface to make the resultant files comply with those standards at the time of image creation.

An additional potential advantage of this system is that the image-input interface can be used as a stand-alone application without communication with an HIS. In this mode, every key-word field must be manually entered by the user, but any file created in this manner would have the same key-word structure as ours. In an attempt to create an interinstitutional, shared, radiographic teaching library,⁴ we are providing other veterinary institutions with the interface software (without HIS communication) for operating the radiograph scanner. Each has used this software to create its own independent teaching library. This has resulted in every file in their libraries being constructed in the same file format, and containing the same key-word structure, as ours. If the images in those libraries were to be placed on a web server, we could have a shared teaching library. In addition to the obvious advantages of providing access to more teaching cases, and to cases with limited geographic distribution, the development costs of new features could be shared. This collaboration could provide more

rapid development in areas such as cross platform compatibility, interfaces to differing HIS configurations, and direct interfaces to other image capture devices (cameras, scanners, etc). Web-based search and retrieval strategies at one institution also could

be adapted to perform at another. Unfortunately, the nontrivial problems of security, intellectual property rights, and patient confidentiality are likely to pose far greater obstacles than technological or file-format compatibility issues.

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