Integration of Content-based Image Retrieval to Picture Archiving and Communication Systems

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Abstract

With the increasing number of digital modalities in routine use, content-based image retrieval (CBIR) is becoming more and more important for electronic patient records and picture archiving and communication systems (PACS). Since robust algorithms for CBIR will be available for clinical routine in the near future, CBIR systems must be integrated within existing PACS environments and the hard- and software used by the physician. In this paper, a general concept for integration is presented that relies on standard protocols and maintains the autonomy of both, PACS and CBIR. Three standard procedures are described for (i) data entry, (ii) reference categorization and labeling, and (iii) query by example. It is shown that this general concept is suitable to integrate the image retrieval in medical applications (IRMA) system to the PACS core that is in use at the Aachen University Hospital, Aachen, Germany.

Keywords: Medical Imaging; Medical Image Archive; Content-based Image Retrieval (CBIR); Picture Archiving and Communication Systems (PACS); Digital Imaging and Communication in Medicine (DICOM)

1. Introduction

There is an enormous need for visual information management in the growing field of digital archives or electronic patient records and by the increasing application domains of medical imaging and telemedicine. In particular, efficient communication and storage of images as well as high level techniques regarding image understanding for image database queries and retrieval are major topics of research [1,2,3]. This newly emerging field combines aspects from databases, image processing and understanding, knowledge-based systems and context-based compression. The challenge in medical informatics is to develop tools for analyzing the content of medical images and to represent them in a way that can be efficiently searched and compared by physicians.

It is well acknowledged that medical image databases are a key component in diagnosis and preventive medicine [4,5]. There is an increasing trend towards the digitization of medical imagery and the formation of adequate archives. The resulting picture archiving and communication systems (PACS) are available across wards within a hospital setting and allow global access to shared resources. Although a PACS relies on complex protocols such as digital imaging and communication in medicine (DICOM), image selection within a DICOM network is based currently on alphanumerical information only. However, information contained in medical images differs considerably from that residing in alphanumerical format. Thus, visual-based (i.e., content-based) indexing and retrieval is expected to have a great impact on medical image databases [6].

The unique characteristics of medical images hinder the direct adaptation of content-based retrieval approaches, which are already in use for unstructured collections of images (e.g., within the Internet). Early systems, such as Photobook [7] or the Query By Image Content (QBIC) of IBM Inc. [8,9] model only a rudimentary understanding of image content. Recently introduced systems for medical image retrieval are text-based [10,11,12], strongly rely on manual input [13], and/or need to be tailored for a specific application and modality (e.g., ImageMatch of MD Online Inc. or the National Medical Practice Knowledge Bank [14] for neuroradiology in computed tomography (CT), the Automatic Search and Selection Engine with Retrieval Tools (ASSERT) and the Image Management Environment (IME) for high resolution CTs of the lung [15,16], or the Generic Multimedia Indexing (GEMINI) for mammography [17]).

Recently, systems have been designed to handle general collections of medical images [18,19]. They operate on local (regional) image characteristics, which are fundamental for diagnostic image interpretation. The interpretation is based on a large amount of a-priori knowledge (e.g., anatomical, physiological). In order to cope with a variety of image contexts (e.g., medical modalities), database schemes have been developed that are generic, flexible, and allow continuous update of the extracted feature sets. In addition, registration of medical images is provided to support many diagnostic queries as well as to detect changes over time. However, the integration of such systems into clinical routine is not addressed in literature so far.

In this paper, we define general interfaces that are required for integration of content-based image retrieval (CBIR) to routine PACS in hospitals. As an example application, these interfaces are specified in detail for the Image Retrieval in Medical Applications (IRMA) system [20].

2. Materials and Methods

Coupling CBIR and PACS can be done on different levels of hard- and software architectures. For the sake of compatibility, both CBIR and PACS must maintain their autonomy as self-standing applications. Information exchange between both components must rely on standardized protocols and should be independent from the actual systems and computer hardware in use.

2.1 System Architecture of Content-Based Retrieval Applications

In order to support browsing of large databases, all approaches for content-based access to images compute a certain set of features, which are stored in the database and linked to the original image. These features represent the image with significantly reduced storage volume and access time. Concerning the integration of medical CBIR systems into PACS, there is no need to analyze whether the features are global, local, hierarchical or of other sophisticated structure. This is handled internally by the CBIR system.

At least two graphical user interfaces (GUI) are provided by medical CBIR systems. On the one hand, manual interaction for data entry, categorization and/or reference labeling of images is supported. On the other hand, image retrieval is assisted by mechanisms for relevance feedback and query refinement. The majority of CBIR systems uses Internet technology to provide such GUIs for data entry and retrieval. Therefore, proprietary applications are not further considered.

2.2 System Architecture of DICOM / PACS Environments

In general, a DICOM-PACS connects imaging modalities, viewing stations, printers and other devices to an archive, which stores both image data and alphanumerical descriptions

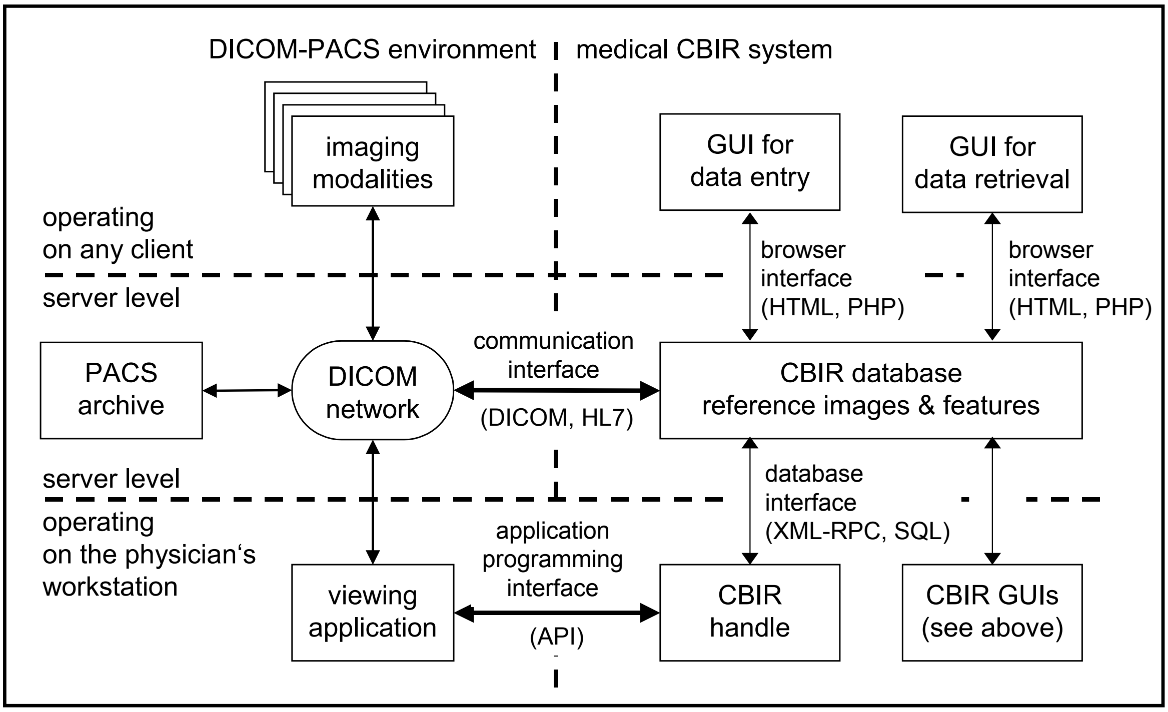

Figure 1: System integration of PACS and CBIR

of study, patient, imaging modality and setup, body region examined, and other information usually used to access the images. In this architecture, the PACS archive is one among other system components, which are all connected within a DICOM network.

2.3 Interfaces

The core of the CBIR system is linked directly to the PACS archive by means of the DICOM and health level seven (HL7) protocols. In other words, the CBIR core is built as a DICOM compliant service class user ordering all information from the service class provider (PACS archive) autonomously, while storage location of image data and patient-related information remains unchanged.

A CBIR handle is designed to run on the hardware, that is in use for PACS viewing stations. This handle is addressed via the application programming interface (API) provided by the PACS core. By means of this API, the unique DICOM identifier of the image object currently displayed is passed to the CBIR system and stored in the CBIR database using the structured query language (SQL). By means of remote procedure calls within the extended markup language (XML-RPC), feature extraction and other CBIR applications can be started. Only this handle needs adaptation when the CBIR is integrated into another PACS.

Since all CBIR GUIs rely on the hypertext markup language (HTML), which is dynamically generated by means of the hypertext preprocessor (PHP), they can be displayed in any Internet browser that is installed on the radiologists' workstation.

3. Results

Figure 1 exemplifies the system integration of PACS and CBIR: The Aachen University Hospital uses a PACS core implemented by Sectra Imtec AB, Sweden (shown on the left hand side). Hence, the PACS-API in use is the Clinical Applications Interface™ (CAI™). On the right hand side, the IRMA system is based on a central relational database, which stores administrative information about distributed objects (data and methods) and query processing (views and jobs). In general, all processing steps of IRMA are regarded as a method transforming either pixel or tree data. Parameters and information on reference images and prototypes are stored in a query view description. Parallel processing on all workstations with installed IRMA daemon is controlled by job lists. In particular, pixel data contains images and feature values, which can be global or local. Tree data holds hierarchical structured regions of interest with mean local features (blobs [21]), which are used for efficient retrieval. Feature methods are either local, global, or universal and produce features on a pixel, image, or set-of-images basis, respectively. Distance methods calculate values representing distance measures between two feature vectors (image data) or two blob structures (tree data). Training methods calculate parameters for classification while classifier methods apply a decision rule based on these parameters. Queries are modeled as a network of interconnected user-implemented methods. By means of job lists, the IRMA system provides automated method transfer to keep all sites up to date and automated job distribution to balance the load of computations [22].

3.1 Standard Procedure for Data Entry

When a radiologist views an image that has been acquired by a DICOM modality, the standard procedure for data entry is started. Note that the protocol used in each step to control the action is listed first:

1. API: pass unique image identifier to IRMA handle
2. XML-RPC: start server programs and
   start standard procedure for reference labeling (if selected)
3. SQL: store identifier in IRMA database
4. DICOM: retrieve source image from PACS
5. compute all features on distributed IRMA workstations
6. SQL: store features in IRMA database

3.2 Standard Procedure for Reference Categorization and Labeling

Within the IRMA system, reference categorization and local labeling of images is possible. However, manual data entry is performed for selected images only. If the radiologist decides to include the current image as a reference, an IRMA browser image is generated on the physician's workstation. The following steps are performed:

1. HTML, PHP: pass image to the Internet browser used as GUI
2. perform manual data entry
3. HTML: pass categorization and labeling information to server
4. SQL: store categorization and labeling information in the IRMA database

3.3 Standard Procedure for Query by Example

Likewise applications for manual data entry (Sec. 3.2), image retrieval is also decoupled from the PACS application for viewing and reporting. The standard procedure for queries by examples runs stand alone but an be initiated within the PACS application:

1. API: pass unique image identifier to IRMA handle
2. XML-RPC: start client program (web browser)
3. DICOM: retrieve source image from PACS
4. HL7: retrieve additional information in alphanumeric format (if required)
5. SQL: select data from IRMA database
6. DICOM: retrieve target images from PACS
7. HTML, PHP: pass data to the Internet browser used as GUI
8. HTML: pass manual interaction (query refinement) to server
   go to Step 5 until result is accepted

4. Discussion

The current approach for integration of PACS and CBIR ensures both systems to stay autonomously. However, further integration is easily possible. Usually, a PACS consists of a DICOM image server and several DICOM-compliant workstations for reading the images and reporting the findings. Basic IRMA components are the relational database, which may be installed on the DICOM server, and the daemons running on distributed machines. Note that idle computational capacities of PACS workstations can be used directly for content-based query processing within the IRMA approach, independent whether the communication is based on the proprietary IRMA protocol or is integrated into standards such as DICOM. For instance, global image analysis may be used to fill or control DICOM header information regarding the imaging modality, orientation, body region examined, or biological system imaged. This information may be wrong in more than 15% of the cases if it is pre-set automatically by the DICOM modality [23].

5. Conclusion

Health information systems aim to present the right information at the right place at the right time to the user [24]. With respect to diagnostic imaging, PACS provides images in a suitable quality for diagnosis to the radiologists in a fast and efficient way. Large efforts have been made addressing the right-place- and right-time-paradigms: ultra-fast networking, sophisticated data storage or pre-fetching mechanisms, and high quality displays. Modern communication protocols such as HL7 and DICOM comprise standardized textual descriptions of study, patient, body region examined, and technical parameters related to the imaging modality. Currently, this is the only information used to select the right information within PACS, i.e. the complete set of relevant images. Since textual descriptions insufficiently describe the great variety of details in medical images, CBIR techniques will have strong impact when integrated into PACS. By means of standardized protocols and the API provided by the PACS core, this integration can be realized to satisfy the right-information-paradigm maintaining the autonomy of both components, the PACS and the CBIR system.

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