

Content-Based Access to Medical Images

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Abstract. With the increasing amount of medical images that are routinely acquired in today's healthcare institutions, common methods of image management become inefficient. Even in modern picture archiving and communication systems that are based on the DICOM standard, image data is addressed by alphanumeric indexes such as patient name and examination date. In this software demonstration, the capabilities of content-based access to medical images is exemplified. Radiographs that are arbitrarily selected from the internet can be compared to the reference database by means of numerical features extracted from the pixel values. This allows for automatic identification of image content such as body region or the biomedical system images, as well as the determination of the modality used for image acquisition. Since the features of the system capture global, local, and structural image properties, content-based access impacts research, teaching and patient care.

Keywords: Medical Image Management, Content-Based Image Retrieval, Segmentation, Classification, Categorization

1. Introduction

Digital imaging has become the most prominent diagnostic tool in medicine. Beside computed tomography (CT) or nuclear medicine, which have always been digital, plain radiography, endoscopy, and microscopy are nowadays captured directly digital, too. Picture archiving and communication systems (PACS) have been established in the hospitals all over the world to manage these information resources. PACS are used to store and handle the images, which are transferred based on the digital imaging and communications in medicine (DICOM) protocol. DICOM supports interconnections of PACS modules from different vendors, e.g. for post-processing of the images and their annotation with alphanumeric attributes such as patient name and study information, image descriptions, and diagnostic reports. This textual information, which is stored within the DICOM header, is currently the only means to access and retrieve medical images from the PACS archive. Since an image tells more than a thousand words, recall and precision of this type of medical image information retrieval is limited in general [1,2].

With this software demonstration, we present intermediate results of the IRMA project (<http://irma-project.org>) for content-based image retrieval in medical

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applications. The IRMA project aims at describing medical images by means of their visual properties in an adaptive multi-resolution approach [3].

2. Material and Methods

Content-based access to images relies on numerical features that are computed from the pixel values. In the medical field, it is difficult to identify the suitable set of descriptive features since the context of images and queries is unknown at time of data entry. Therefore, the IRMA concept is based on an adaptive multi-scale analysis.

2.1. Global Features

In a first step of processing, the images are categorized according to a terminology consisting of four orthogonal axis covering the anatomy (A) and bio-system (B) shown in the image as well as the creation (C) and direction (D) of imaging [4]. This is done based on global image features, i.e. a feature vector is assigned to the entire image. For each category, a global proto-type is defined and used for both geometry and contrast registration of the images. Relying on a reference database of more than 15,000 radiographs that have been ABCD-classified by trained radiologists, an unseen image is categorized automatically. Currently, this categorization can be performed with an error rate of about 15%, 9%, or less than 5%, if the best match or a set of the five or ten best matches is considered, respectively [5].

2.2. Local Features

The next part in the chain of processing extracts local image features. In contrast to the previous stage, a feature vector is now assigned to every pixel within an image. Based on an initial watershed segmentation, a region merging scheme is applied until the entire image is represented by a single region [6]. This final stage is considered as the root node of a hierarchical attributed region adjacency graph (HARAG), which is obtained directly from logging the merging steps. Features such as size, position, shape, or texture are used to describe the regions, which represent single objects [7]. From the automatically computed regions, objects are extracted by classification of the attribute vectors [7,8]. By separating these two steps, the user's knowledge of the image content becomes a classifier. On a low-level, manually generated interval queries can be performed. On a high level, supervised learning by the support vector machine, the nearest neighbor, and the Bayes classifier are available. Edge attributes such as the normalized distance, the angle between two regions' main axis, or the relative gray scale are used to represent spatial and/or temporal relations between individual objects (scene description [9]).

2.3. Structural Features

In order to incorporate medical a-priori knowledge on a higher level of semantics, structural prototypes are trained from manual reference segmentations in each of the categories. As a result, a pruned HARAG is obtained where node and edge attributes are represented by Gaussian mixture models (GMM). Accordingly, image similarity is

expressed by means of graph to sub-graph matching techniques. In particular, a neural network based on the approach of Schädler and Wysotzki [10] is used to efficiently compute the graph-based image similarity [9].

3. Results

Currently, internet-based demonstrations are available for image access based on global features. The capabilities of local and structural features will be exemplified using platform-independent Java applications.

3.1. Global Features

Content-based image retrieval in medical applications that is based on global similarity has been established successfully and is available as online demonstration at http://irma-project.org/onlinedemos_en.php. Query images can be selected from the local hard disc and transferred into the system (Fig. 1a). The query response is calculated immediately within only a few seconds (Fig. 1b). All user interaction is protocolled to allow to step back to any past state of the system, as well as boolean combinations of those (Fig. 1c). This principle is called extended query refinement [11].

3.2. Local Features

Content-based image retrieval based on local features is used for quantitative and qualitative analysis of contained objects. On a set of 105 radiographs of human hands, which were extracted arbitrarily from the categorized IRMA database, a manually generated query for the metacarpal bones, based on 25 sample regions, results in a recall of 0.6 and a precision of 0.53 [7]. The best result for automated training was obtained by the support vector machine with a recall of 0.58 and a precision of 0.67 based on 50 training regions [8]. By separating image partitioning and classification the training of the classifiers is focused on the attribute vectors and no low-level knowledge on image processing is required. Moreover supervised training is efficiently performed by point & click training of sample regions.

3.3. Structural Features

Content-based image retrieval based on structural information is still in development. First results are obtained from standardized plain radiographs of human left hands, which are acquired routinely to determine the bone maturity of infants. Based on manual reference segmentations of 96 hand radiographs, in total 1,289 individual bones have been identified and labeled. The structural category prototype is computed and used to extract relevant regions from HARAGs of unseen query by example (QBE) images. It is shown that this kind of scene analysis on a high level of semantics outperforms content-based image retrieval (CBIR) that is only based on descriptions of relevant objects by single regions [8]. Also, it can be adapted to any local pattern that may be of interest in the QBE image.



Figure 1: An x-ray image of the skull is searched via Google (a), transferred to the IRMA content-based image retrieval system, and similar images are retrieved from the system (b). The sliders below each responded image allow for interactive query refinement. All interaction is protocolled and allows to restore any system stage of the session (c).

4. Discussion

Smeulders et al. have addressed the general problems related with CBIR systems, i.e. to bridge the sensory and the semantic gap [12].

The semantic gap opens between the high-level content understanding of human observers and the low-level nature of numerical image features. In our approach, it is bridged by the multi-level nature of processing. Determining image similarity based on global features allows for automatic categorization of images, if a reliable database of a priori classified images is available. By means of this knowledge, further processing steps can be parameterized adaptively.

The sensory gap is the gap between an object in the world and its recording as an image. More precisely, the sensory gap addresses problems related to the resolution. In the same radiograph, sometimes small and sometimes larger details are important, such as nodules within the lung, or size and position of lung in a chest x-ray, respectively, depending on the user's context. This gap is closed by the multi-scale nature of local features.

5. Conclusion

In conclusion, a novel concept of automatic image content modeling by global, local and structural information is proposed. A reliable proof-of-concept is given for global categorization in categories of radiological terminology [3] and bone maturity assessment [7]. Both are comprehensively evaluated using a large set of ground truth radiographs. However, the IRMA concept of attributed graph-based modeling of image content is rather general. For instance, it can be used directly to empower physicians for interactively marking a region of interest (ROI) within the QBE image to be diagnosed, and retrieving images from the PACS archive containing similar local patterns. Allowing access to the corresponding medical records, this will impact diagnostics, research, and medical education. Furthermore, the management of multimedia information resources is augmented.

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