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An MPEG-7 Image Retrieval System of Atherosclerotic Carotid Plaque Images

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Abstract - **This paper proposes an MPEG-7-based ultrasound image retrieval system which can assist in studying and analyzing images from atherosclerotic carotid plaques. The proposed system is able to retrieve and sort ultrasound images of the atherosclerotic carotid plaques using image texture analysis features and the KNN classification algorithm. The prototype system was evaluated on a database of 274 images of symptomatic and asymptomatic plaques and the results show the efficiency and efficacy of the proposed approach. The best percentage success rate of correct retrievals was obtained for the NGTDM, followed by the SGLDM (range) feature sets with the corresponding scorings of 70%, and 68%, respectively. The proposed system can be very useful to physicians who, in order to select the best treatment strategy and therapy for a patient, need to find and analyze related cases.**

Keywords-Carotid plaque, ultrasound image retrieval, MPEG-7 image encoding

I. INTRODUCTION

High-resolution ultrasound has made possible the noninvasive visualization of the carotid bifurcation and for that reason it has been extensively used in the study of arterial wall changes; these include measurement of the thickness of the intima media complex (IMT), estimation of the severity of stenosis due to atherosclerotic plaque and plaque characterization [1]. Applications of carotid bifurcation ultrasound include: i) identification and grading of stenosis of extracranial carotid artery disease often responsible for ischemic strokes, transient ischemic attacks (TIAs) or amaurosis fugax (AF); ii) follow-up after carotid endarterectomy; iii) cardiovascular risk assessment: the presence of carotid bifurcation atherosclerotic plaques is associated with increased cardiovascular mortality, and other.

In our days, a huge volume of data, concerning images of carotid arteries, is available in digital records and professional databases. The value of this information depends on how fast we can find, retrieve, process and analyze data of interest. This paper proposes a Content-Based Medical Image Retrieval (CBMIR) system, which allows doctors to search and retrieve ultrasound images of atherosclerotic carotid plaques based on the texture characteristics of the images. The system uses the MPEG-7 [2], [3], [4] standard to describe semantically and syntactically the medical images and embedded classification algorithms use the MPEG-7 metadata to classify and sort the results to assist in the decision support. This paper presents the design of the architecture, its corresponding implementation and discusses the experimental results carried out with the web-enabled prototype system of the proposed architecture.

The paper is organized as follows. The following section discusses related work in image retrieval systems, section 3 presents the proposed CBIR system, section 4 presents the evaluation of an online CBIR prototype system of and section 5 concludes and presents future work and development.

II. PREVIOUS WORK

During the last 20 years there has been major research effort undergoing in the field of Content Base Image Retrieval (CBIR) systems [5], [6]. Muller *et al.* [6], for example, presented an evaluation of the CBIR applications on medical imaging and the benefits that can be gained from their usage. In this section, selected relevant CBIR systems are briefly presented.

CBIR applications for ultrasound imaging of the atherosclerotic carotid plaque were studied by [7], and [8]. Amores *et al.* [7] presented a CBIR system that uses the image diagrams to extract local, global and other characteristics of the ultrasound images. The histogram and the morphology of the image can be used to extract additional knowledge of a new image. Christodoulou *et al.* [8], proposed a CBIR system based on texture and morphological analysis, for the retrieval of ultrasound plaque images of the carotid.

Jennifer G. Dy *et al.* [9] implemented a hierarchical approach on image retrieval called CQA to retrieve lung images. This technique uses multiple groups of features and a two-phase approach to retrieve the images based on ontological queries. The creators of CBMIR [10] proposed a medical standard to describe the CT brain scan images based on the MPEG-7 and DICOM standard and the semantics features of the image. Other, non-medical CBIR applications include the work of Nezamabadi-pour and Kabir [11], which used the histogram of the image to retrieve similar images. Laaksonen *et al*. [12] that implemented the PicSom CBIR application which uses self-organization maps (SOM) and image characteristics to categorize the images into groups.

Most of the above approaches extract the semantics of medical images and store them as raw data in relational databases.

The work presented here is an extension of work presented previously by our group Christodoulou *et al.* [8], [13].

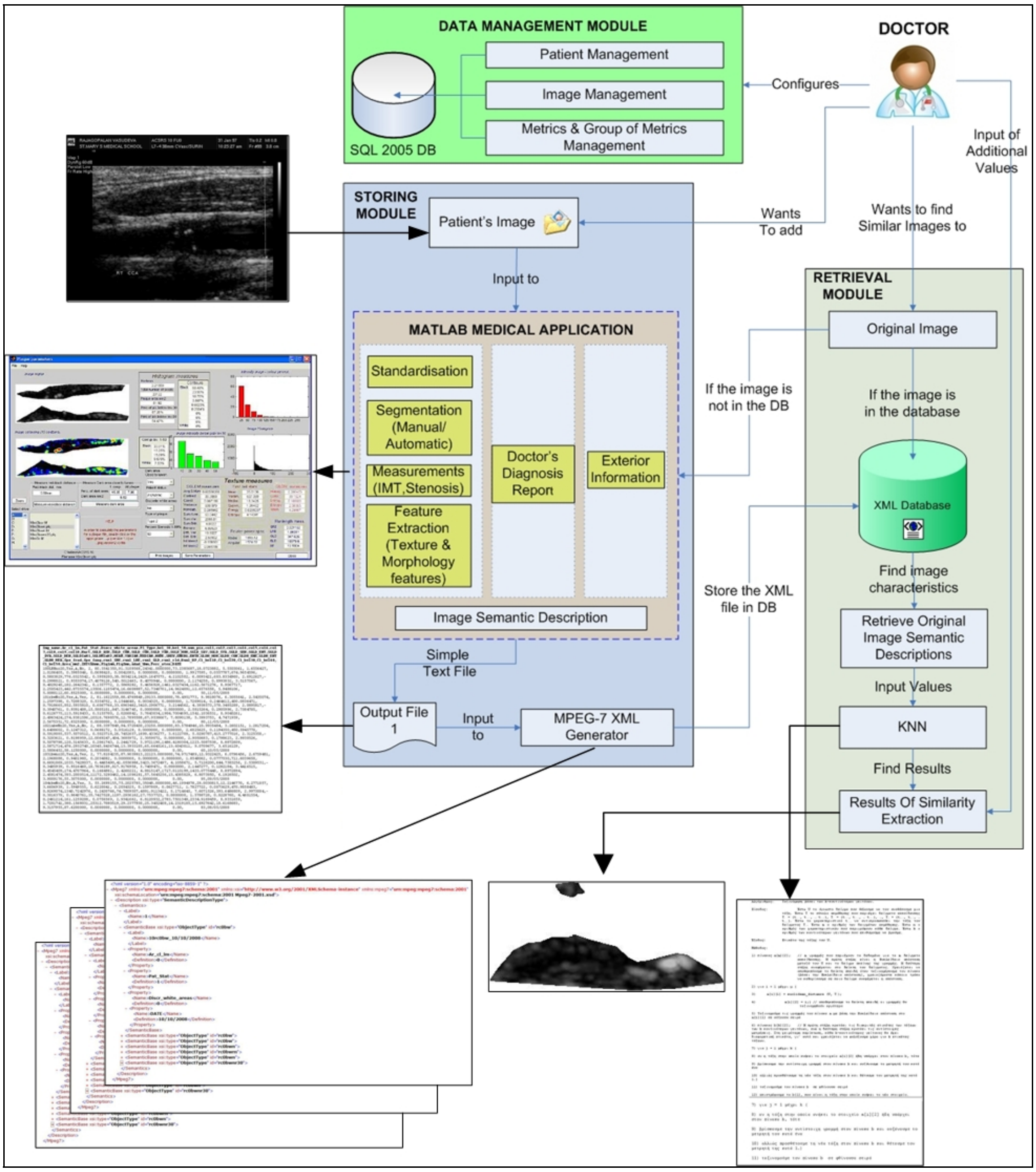

Figure 1. Bird's eye view of the proposed CBMIR system architecture. The system mainly consists of the *data management module*, *the storing module*, and *the retrieval module*. The *storing module* is using a Matlab® *based image processing application* to extract and store image texture characteristics.

This approach creates valid MPEG-7 xml files that describe the semantics of the images and group the images into various categories based on the images' semantics; the results are used to improve the efficiency of the retrieval algorithm. The next section describes the proposed approach.

III. CONTENT-BASED MEDICAL IMAGE RETRIEVAL SYSTEM

A. Overall System

This section describes the design and implementation of the proposed medical image retrieval system. The proposed system retrieves and sorts medical images according to the user query and the semantics of the medical images described using the MPEG-7 standard. The semantics of the medical images are generated from the output of the medical analysis system, i.e. "Plaque Texture Analysis, Image Analysis Program for Ultrasonic Arterial Wall Changes and Atherosclerotic Plaques" [14], [15]. This medical analysis system processes the ultrasound atherosclerotic carotid plaque images and extracts their characteristics about the texture, the morphology, and the histogram. Basically, it normalizes the image histogram and then allows the manually or automatically mark of the image to sections, in order to isolate the part of the image that contains the plaque for further processing. Then, it calculates a number of shape metrics, such as the area of the plaque, and other. Finally, it processes and analyses the texture characteristics of the atherosclerotic carotid plaque as documented in the following subsection (see section III.B).

The main architecture consists of three major modules: the *storing procedure module*, which creates the MPEG-7 xml files, the *data management module*, which manages the patient and image data of the application, and the *retrieval process module*, which incorporates the algorithms that retrieve and sort the relevant data according to the user query. Figure 1 shows the proposed architecture.

B. Texture Features

Initially several image texture analysis features were extracted and used in the statistical analysis [15], [16]. These features have been presented in previous studies. The algorithms used namely are: 1) Statistical Features (SF), 2) Spatial Gray Level Dependence Matrices (SGLDM) algorithm (mean and range values), 3) Gray Level Difference Statistics (GLDS) algorithm, 4) Neighbourhood Gray Tone Difference Matrix (NGTDM), 5) Statistical Feature Matrix (SFM) method, 6) Laws Texture Energy Measures (TEM), 7) Fractal Dimension Texture Analysis (FDTA), 8) Fourier Power Spectrum (FPS), 9) Run Length Statistics (RUNL), and10) Plaque Shape Features (SHAPE).

Then, both the data and several other calculated metrics like the area of the plaque in mm^2 are described in a simple text file, which is used as an input to the proposed system.

C. Storing Procedure Module

The *storing procedure module* parses the text file into a valid MPEG-7 file [2], [3]; the generated xml file describes syntactically and semantically the atherosclerotic carotid plaque shape and texture features, e.g. the SGLDM and the GLDS; the data can be accessed using XML languages, like XPath and XPointer. Each xml file describes the atherosclerotic carotid plaques of a specific patient and includes the comments of only one doctor, i.e. the patient's doctor. Thus, additionally, each MPEG-7 xml file includes details about the doctor, e.g. id number, name and surname, using the *SemanticDescriptionType* of Data Description Language (DDL) [4]. To describe the images and their characteristics, the storing procedure module uses the semantic type *ObjectType*. The architecture uses a relational database to store the directory paths of the generated MPEG-7 xml files.

D. Data Management Module

The *data management module* manages all the data that are necessary for proper operation of the proposed CBMIR system, such as the user data. This module consists of the patient's personal data, the patient's image data, the medical metrics and the assigned groups of metrics. A medical record for every patient is also stored in the database. Atherosclerotic carotid plaques previously analyzed by our system, are saved in a data store which is also controlled by the data management module.

E. Retrieval Process Module

The *retrieval process module* allows the users to retrieve similar plaque images by creating a search question. In order to find similar images the users create the query by choosing an atherosclerotic carotid plaque image, and the similarity criteria (i.e. carotid plaque texture metrics) that must be considered during the retrieval process. At this point, the users, e.g. the doctors, can specify the metrics, that are going to be used by the k-nearest-neighbors algorithm (KNN) algorithm to classify the images of the database.

Following this, the retrieval process creates an equivalent XPath expression for retrieving the semantics from the MPEG-7 xml files. The retrieval process executes the created XPath expression only on the xml files which were created by the same user who initiates the retrieval process. This means that a doctor can access xml files that were created using his/her account; future work will consider the safe and proper exchange of medical data between different doctors. The XPath expression applies both to the MPEG-7 xml file of the input image as well as to the rest of the MPEG-7 xml files that are stored in the application server (image pool). The results of the XPath expression are returned to the MPEG-7 search engine, which calls the KNN. The KNN algorithm takes as input the results of the XPath expression for the input image, the results of the XPath expression for all the atherosclerotic carotid plaque images of a specific doctor, and the requested by the user, number of image results (K). When the KNN algorithm is executed on the above data, the K most similar images to the input image are retrieved, sorted and displayed to the screen.

IV. EVALUATION

A. Image Dataset

A total of 274 carotid plaque ultrasound images (137 symptomatic and 137 asymptomatic) were analyzed. The carotid plaques were labeled as symptomatic after one of the following hemispheric or retinal symptoms was identified in a follow up period of 6 to 84 months: stroke, transient ischemic attack or amaurosis fugax. Patients with cardioembolic symptoms were excluded from the study. Asymptomatic plaques were truly asymptomatic if they had never been associated with symptoms in the past [17], [18].

The ultrasound images were collected in the Irvine Laboratory for Cardiovascular Investigation and Research, Saint Mary's Hospital, UK, using an ATL (model HDI 3000 - Advanced Technology Laboratories, Seattle, USA) duplex scanner with a 5-10 MHz multifrequency probe at a resolution of 20 pixels/mm. The images were normalized manually by adjusting the image linearly as described in [19]. This normalization was necessary in order to extract comparable measurements in case of processing images obtained by different operators or different equipment.

The plaque identification and segmentation tasks are quite difficult and were carried out manually by the expert physician and/or vascular ultrasonographer based on color flow imaging.

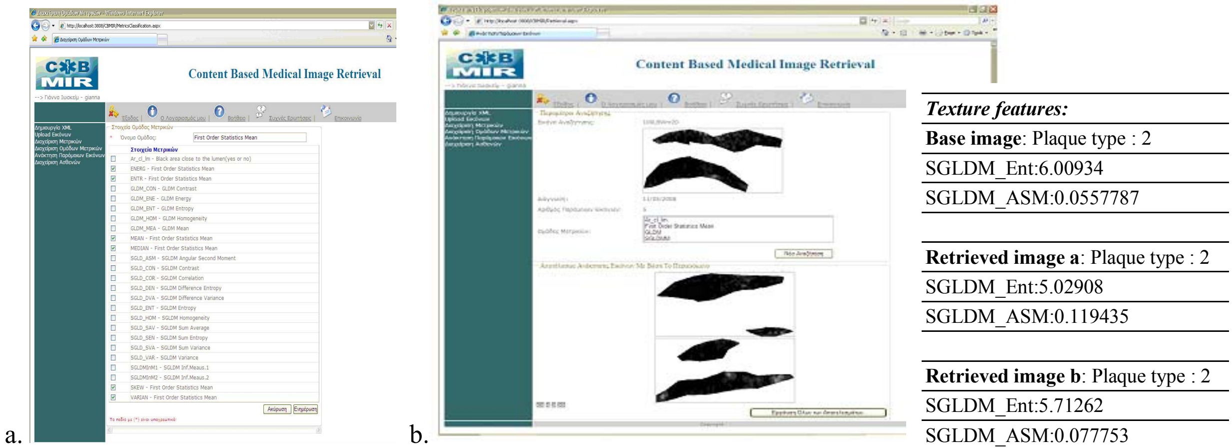

Figure 2. Main functionalities of CBMIR system. a) selection of texture features to be used for the retrieval of an image from the database, b) retrieval of similar images (the image at top is the image we have as a base (or reference) image and for this image the system was able to retrieve five similar images, the two are displayed at the bottom of the screen while the rest can be seen if we choose to continue main features associated with image are seen on the right hand site.

B. *Overall System*

The final implemented CBMIR system is an online tool created with Microsoft® ASP.NET and Microsoft® SQL Server. The image features and metrics are extracted using an ultrasound image processing application which was created using Matlab® [15], [14]. This system was integrated to the CBMIR system using Matlab components for .net. A group of initial users were created in order In order to do the initial tests. Some sample xml files using medical images were extracted in order to verify the procedure.

The usage scenario is as follows: Initially the user has to register in the system. After the registration he/she will be able to create the XML files by adding as input the results from the ultrasound image processing application. Through this phase the user will also be able to manage the metrics and group of metrics he/she wishes to utilize.

Furthermore, the doctor is able to manage patient's medical data and personal information. After entering all the mandatory data to the system, the doctor can search, based on specific criteria, for similar atherosclerotic carotid plaques. Figure 2 presents screen shots from the application. Figure 2a is the screen being used in order to select features to be used during the search and figure 2b shows the initial image and a group of similar images our application that shows the procedure described above. At this point each doctor has access only to his patient's data. In order to evaluate our system, we have used the ultrasound images collected at Irvine lab, Saint Mary's Hospital, London, UK, as documented above in section IV.A. We have used the black box evaluation technique on the three modules of the application covering all aspects of the CBMIR functionality.

C. *Storing Procedure Module*

To evaluate the *storing procedure module* we have created MPEG-7 xml files that included all the semantic and syntactic characteristics of an image, such as the plaque texture and shape features described above, and the area of the plaque. We have checked that all the semantics were included correctly in the MPEG-7 file and finally we have validated each MPEG-7 file using an official on-line MPEG-7 validation [20], which showed that the storing procedure creates valid MPEG-7 files. The time needed to create an MPEG-7 xml file is negligibly small.

D. *Data Management Module*

To evaluate the *data management module* we stored the patient's medical records to the database as well as the doctor's accounts and the links to the MPEG-7 files. It was verified that data and records are stored in a valid form and the system prevent users from entering non-valid data.

TABLE I. PERCENTAGE SUCCESS RATE OF CORRECT RETRIEVALS OF THE *RETRIEVAL PROCESS MODULE* BASED ON THE TEXTURE FEATURE SETS USING THE KNN MODEL WITH K=7 (RESULTS TABULATED ARE BASED ON 274 IMAGES AND THE LEAVE-ONE OUT METHOD).

Feature Set	% Success Rate of Correct Retrievals
SF	60%
SGLDM (mean)	65%
SGLDM (range)	68%
GLDS	61%
NGTDM	70%

E. *Retrieval Process Module*

Finally, to evaluate the *retrieval process module*, we created search questions and retrieved the images from the MPEG-7 xml files. By including more metrics in our query, the search results were more specific. The resulting images matched the search query based on the KNN algorithm which provides relevant results Table I tabulates the percentage success rate of correct retrievals based on the texture feature sets using the KNN model with K=7. The results tabulated are based on 274 images and the leave-one out evaluation method. The best percentage success rate of correct retrievals was obtained for the NGTDM, followed by the SGLDM (range) feature sets with the corresponding scorings of 70%, and 68%, respectively. Because the KNN algorithm does a linear search on the MPEG-7 xml files, a large K number needs more time to calculate the results than a smaller one. Also more time is needed when we specify more groups of semantics (feature sets) to be included in the search query.

V. CONCLUDING REMARKS

This paper describes an architecture that creates stores and uses MPEG-7 medical images and allows the retrieval of the k-most relevant medical images according to a user query. The MPEG-7 xml files describe the semantics of the carotid plaque images; each MPEG-7 file describes the atherosclerotic carotid plaque images of a patient as annotated by his doctor.

Because the architecture incorporates the usage of MPEG-7, the MPEG-7 data can be used by other applications that use the MPEG-7 standard. The time needed to store and retrieve the MPEG-7 file is quite low. The XPath language helps maintaining the retrieval time in a low level. On the other hand because the KNN algorithm calculates the distance between every image in the database pool, a large amount of time is needed when we are handling a large database pool. The best percentage success rate of correct retrievals for the KNN classifier with K=7 was obtained for the NGTDM, followed by the SGLDM (range) feature sets with the corresponding scorings of 70%, and 68%, respectively

Future work will consider expanding the proposed architecture with additional features. For example, during the creation of the MPEG-7 xml files, the architecture can take into account information retrieved automatically from external sources, e.g. using DICOM [21] it can use information about the origin of each image. Furthermore, the classification algorithm will use the user experience to further customize the display of results.

Future work will also carry out more experiments to validate the architecture and compare its performance against other similar approaches. We are currently investigating the integration of the self-organizing maps, which can capture the knowledge over time and can provide results in shorter time than the KNN algorithm. The retrieval process will be expanded to return not only the values of the texture characteristics that are used in the search query, but also additional information about the returned images; this will help the doctors to determine the best treatment for their patients.

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