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The Application of Artificial Intelligence Techniques to Automatic Angiography Analysis using PACS to establish a Score for the effect of Coronary Stenosis TIC2003-07593

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Abstract

The aim of this project is to develop a system making it possible to detect and establish a quantification pattern for the effect of coronary stenosis. In doing so it was first necessary to set up a PACS (Picture Archiving and Communication System) developed ad hoc by the research team for the Hemodynamics Service of the Juan Canalejo University Hospital Complex in A Coruña, Spain, in order to be able to acquire and treat the angiography studies.
In this project, a system is being developed to help with the decision made by arterial models for patients, using image segmenting techniques and arterial labelling. Afterwards, algorithms are applied for detecting stenosis in the arterial tree. The precise quantification of this ratio makes it possible to make a much more precise diagnosis, avoiding having to carry out additional tests on the patient, with the subsequent saving of hospital resources.

Keywords: Angiography, Digital Image, Stenosis, Digital Image Processing, Digital Medical Images, PACS

1 Aims of the Project

General Aim

Cardiac illnesses are pathologies of major social importance that represent an ever-increasing segment of health costs. Angiographies are commonly used in the diagnosis and prognosis of these illnesses, carried out by hemodynamics units.
Most hospitals use angiographs with a single arm that generate 2D images from different perspectives. The Cardiologist then uses this to calculate a risk score depending on the 'post-stenosis' cardiac zone using a method that considers arteries that are proximal and distal to the

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stenosis. This score is an estimate, which depends on the anatomy observed in the arterial tree and the position of the stenosis in the tree.
This project takes as its starting point that it is possible to develop an automatic system to support the decision-making process in the field of medical diagnoses for ischemic cardiopathies.

Specific Aims

1. Implantation of the PACS developed by the research team (as mentioned in the Introduction) in the hospital's communications network in order to acquire and store DICOM hemodynamics studies.
2. Segmentation of the coronary arterial tree using different digital image processing techniques. Using the infrastructure referred to in paragraph 1 above, a database of patients will be created with the angiographic studies and segmented images.
3. Using this information, the aim is to create an arterial model for each study making it possible to adjust the diagnosis to their particular anatomical features. Analysis will be made using this model in order to locate stenoses.
4. A knowledge-based system will then be developed capable of calculating the risk of coronary accident. This is carried out via the assisted quantification how severely the cardiac muscle is affected in the "post-stenosis" zone. Here the aim is to automatically emulate the system for quantifying stenosis currently used in clinical practice. This system may be used to support the doctor's decision in order to make a more objective and independent evaluation than that currently being made, for which Artificial Intelligence techniques will be used.
5. Developing new risk score patterns based on the information taken from the database of images developed. The systems currently in use for making risk evaluations are based on the visual analysis of images and evaluation of the parts of the arteries with and without stenosis. In this project, new quantification systems will be sought based on the use of image processing techniques and the status of the arterial tree (position of the stenosis, degree of occlusion, etc.).
6. Finally, the development of this system will facilitate access to clinical records, including angiographic images, by other hospitals, thereby assisting in inter-hospital consultations and the process of obtaining second opinions. Making data available over the Internet opens the way to implanting telemedicine consultations while only making minimum changes to the existing system.

2 Level of success achieved by the project

In line with the aims defined above, the project has developed in two main directions:

2.1 Information System (PACS)
Development of the system for acquiring, storing and accessing the hemodynamics studies produced at the Juan Canalejo Hospital. This platform serves as the foundation over which specific tools are being developed to achieve the second goal of the project. This is now almost complete and operating at test stage in the hemodynamics unit at the hospital. One system is in use that is already storing all of the angiographic studies produced by the two rooms in the unit. The other room creates analogical studies, and work is underway to define a protocol that easily digitalizes and standardizes these studies to DICOM for their subsequent integration.

This system gives doctors access via an interface to all of the hemodynamics studies produced at the hospital for their study and diagnosis. This makes it possible to eliminate the present conventional storage system, which stores each patient's data on a CD-ROM, leading to problems both in the time taken to access studies as well as with storage space. This manual system is currently being replaced by access to a PACS, thereby overcoming the deficiencies that exist at present. The tool that has been designed makes it possible to access the PACS and to create new sequences of frames, and to create diagnostic reports associated with the patient's study. It also makes it possible to modify the frames' adjustments, facilitating the diagnosis of the cardiopathy made by the specialist [1][2]. Figure 1 shows an example of the interface currently in use:

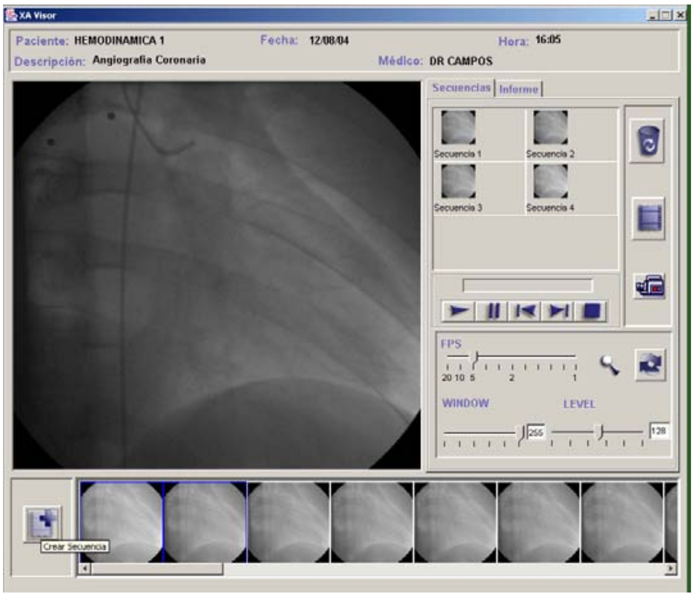

Figure 1. Interface used for access to hemodynamics studies

Study to assess the dimensions of the storage system for studies carried out at the Juan Canalejo Hospital Complex

Medical personnel were questioned about the number of studies made on a yearly basis in their unit, how long they lasted, the estimated size of these studies, and the number of series each contained. This information may be summarized as follows:

- The load on the exploration rooms is approximately equal, with around 50% of the studies being carried out in each.
- The number of studies carried out yearly, including diagnoses and angioplasties, is approximately 3700 (2600-2700 diagnoses and 1000 angioplasties). This number is subject to a degree of random variation, depending on breakdowns in the system, tending to rise each year.
- The study lasts 25 seconds for a diagnosis and another 25 seconds if an angioplasty is also carried out.
- The size of the information produced in each study is unknown by the specialists.
- The number of series in each study varies from case to case, as more than one is taken, varying parameters until the necessary information is obtained to make a correct diagnosis.

- Each series lasts between 4 to 5 seconds for diagnostic cases, and around 6 for those from orthographies.
- The studies have been stored on CD-Rom since the end of 2000.

30 CD-ROMs were then randomly selected in order to estimate the average size and duration of the studies. The results obtained are given below_

- Average space occupied per study (including DICOM file viewer): 169.46 Mb
- Average duration of each sequence recorded at 12.5 images per second: 3.888 s.
- Average duration of each sequence recorded at 25 images per second: 4.098 s.
- Average total duration of a patient's study: 72.093 s.

Taking this information into account, it may be deduced that the idea of the specialists regarding the duration of each sequence is very approximate. Also, the total duration of the studies is clearly underestimated. As for the total amount of information created, it may be concluded that some 488 Gigabytes are produced per year [3].

2.2. Processing tools

Involving the development of tools for processing angiographic images to degree how seriously the cardiac muscle is affected by stenosis. Vascular segmentation and the evaluation of lesions is a field in which continuous research is carried out, and in which there is room for major improvements such as combining techniques, working with various images, labelling, etc., providing more complete information and helping to improve the segmentation process by automating the detection of stenosis or locating it in the coronary tree. For this reason, this project is currently focusing on the implementation of different digital image processing techniques (classic algorithms, artificial neurone networks, deformable models, etc.), in order to determine which solution or combination of solutions is the most effective.

Different techniques and vascular segmentation algorithms have been tested, which may be categorized as follows:

- "pattern-matching" techniques
- model-based methods
- tracking-based methods
- methods based on AI
- methods based on artificial neurone networks
- methods for detecting miscellaneous objects with tubular structures

The algorithm that has provided the best results and which has been most widely used to date is within the techniques of pattern matching (based on the skeleton and the growth of different regions), as well as techniques based on tracking [4].

The trials carried out to date, using a technique designed for the segmentation of coronary angiographies, allow experts to initiate and guide the semiautomatic detection of the borders of vessels. Once satisfied with the segmentation, the location of the stenosis is marked on the image, applying an algorithm that will evaluate its impact depending on its location, helping to calculate the risk of cardiovascular problems associated with the situation of the stenosis in the coronary tree. The results from semi-automatic detection have generally been satisfactory in images showing a visible structure of connected vessels. The evaluation made with the expert, comparing the results of evaluating three images using this technique and three without using it, has shown that the cases considered as most serious by the expert corresponded with the highest cardiac disease values obtained by the algorithm, and equally for the most serious lesions. These results suggest the suitability of cardiac disease as a diagnostic tool and the impact this represents, and therefore the continuation of this line of work.

This said, the results obtained to date have presented a series of difficulties:

Difficulty of generalization: correction vs. usability: Visually analyzing the result of segmentation, we have been able to observe the extraction of background structures, such as submillimetric vessels or random structures present in the background of the image.

Computational difficulties derived from the type of image: Errors in extraction are mainly due to the lack of local contrast in the image and the lack of a priori anatomical knowledge, making it impossible to distinguish the vascular segments from different areas of the background of the image (such as bones or muscle tissue) when viewed locally; this means what at first appears simple becomes immensely complex when implementing it within the context of a computer model.

Final results strongly dependent on segmentation: The computerized techniques for evaluating coronary illnesses using X-Ray images have to guarantee a high level of accuracy and the ability to be reproduced, necessary in order to evaluate the progress of the illness or to decide if surgery is necessary. In this case, the values for cardiac disease are obtained from a series of calculations based on the segmented image, only depending on the correction and complexity of the segmentation and the diagnostic value of the image selected [5].

The series of images below shows how the processing technique currently in use works:

Figure 2. Automatic initiation of coronary vessel tracking

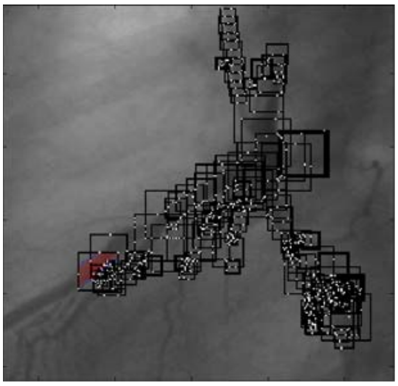

Figure 3. Result of automatically tracking the coronary tree

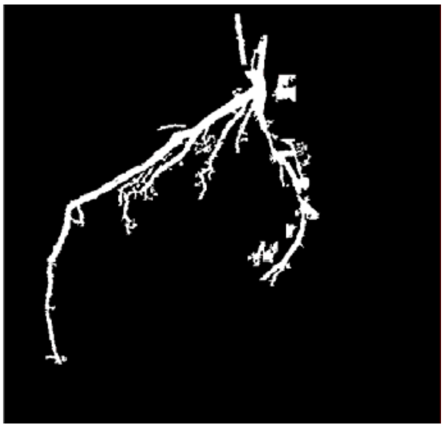

Figure 4. Mask of the tree structure detected

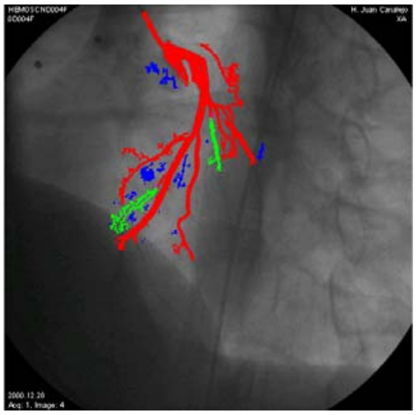

Figure 5. Result of automatic tracking.

automatically
When the system completes the automatic detection of the coronary tree (figure 2 and figure 3), the system presents a mask of the information obtained (figure 4). This mask is then placed over the original image, where the specialist must manually mark the point where the stenosis is located (figure 5). Once the specialist has located the stenosis on the segmented image, the algorithm quantifies its risk by calculating the percentage of pixels affected (in green) from the total number of pixels in the tree (those in green plus those in red). The blue pixels are segmented but not connected to the tree, and therefore are not included in the calculation. The score is provided for each stenosis and the degree to which all of those present are affected, which in this case, without some being contained in others, corresponds to the total of their scores (Table 1):

Table 1. Results of analysis with two stenoses

Stenosis	**Risk**	
1	6.92	**Total affected: 11.25%**
2	4.33	

3 Indicators of Results

Personnel being trained:

a) Presentation of the Doctoral Thesis entitled "**A new perspective on developing an information system for medical images. A tool to support making clinical decisions**" June 2004

b) Presentation of the Doctoral Thesis entitled "**Study and validation of advanced segmentation algorithms in biomedical images. Integration in a computer system**" June 2004

Training has also been given to numerous graduates in Computer Engineering or Technical Computer Engineering by project researchers for their degree projects, in which the main subject is directly related to the project and their results applied to it:

- Development of a system for handling medical images (PACS) based on the DICOM standard and its implantation in the San Rafael Medical Institute of Surgery in A Coruña. January 2005. Definition of an architecture for the integration of digital image processing algorithms with different computing requirements in Web systems. January 2005.
- Study, implementation and testing of safety mechanisms necessary for the transmission of clinical data in DICOM format, in line with Spanish legislation on the protection of personal data. January 2005
- Development of an information system for patients with colorectal cancer, integrated in the global Colon Cancer Family Registry of the National Cancer Institute in the USA. January 2005
- Web environment for developing medical research studies, based on computer measurement of radiological images integrated in a hospital PACS. Example of a study for the implantation of a knee prosthesis. July 2004
- Development of a technique for evaluating coronary stenosis with hemodynamic images. Integration in an Information System for medical images. July 2004.
- Integrated environment in a PACS for editing hemodynamics studies in DICOM format on digital video. September 2004

Another important aspect is the mobility of the team's researchers, visiting other research centres, or welcoming researchers from other centres.

- Visits: Prof. Alejandro Pazos. Jun 2004 and Jun-Jul 2005. Georgia Institute of Tecnology. USA
- Visits from other researchers: Prof. Ezquerra. Georgia Institute of Tecnology. Sept-Oct 2004 and Sept-Dec 2005

The head researcher involved in this project is the coordinator of the project "**A pilot study of Colorectal Cancer in Galicia, Spain**" lasting two years and fully funded by the NIH-USA for a total of $162,440. This pilot project is taking place as part of Galicia's involvement in a worldwide project with five participants that has been underway for some years, with several millions of Dollars of funding per year.

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