A SEMI-AUTOMATIC TOOL FOR THE DETECTION AND QUANTIFICATION OF STENOSIS

S. Fernández, A. Castro and B. Arcay

Department of Information and Communication Technologies, Faculty of Computer Science, University of A Coruña, A Coruña, Spain

sfdelavega@udc.es, alfonso@udc.es, cibarcay@udc.es

Abstract: This work presents an application that was developed by our research team in collaboration with cardiologists specialized in the analysis of hemodynamics images. The purpose of this application is to improve the analysis of the images by means of a semiautomatic mechanism that helps the medical expert to assess the importance of possible stenoses in the coronary tree. The application provides an initial detection of the arteries that subsequently can be corrected by the specialist; on the basis of this detection, the system calculates the extension of the area that is affected by the stenosis and helps the expert establish a diagnosis.

The application was developed according to a web-oriented paradigm, which is familiar to most users, and implemented with JAVA language.

Introduction

In many developed countries, cardiovascular pathologies are among the most preoccupying health problems, in particular for the sanitary institutions that dedicate a considerable part of their resources to their treatment [1][2]. One of the most recurring coronary lesions is stenosis, the narrowing of an artery, whose prognosis largely depends on the severity and the extension of the affection.

The myocard is irrigated by two arteries that originate in the aorta and extend over the epicard: the right and left coronary artery. However, since the left coronary artery divides into two ramifications (the anterior descending artery and the circumflex artery), experts count three coronary blood vessels, as can be seen in Figure 1. The blood vessels are divided into three portions according to the distance from their origin: proximal, medial, and distal. The development of arteries and their ramifications is different for each individual [3].

Among the most frequently used techniques for patient diagnosis is the use of hemodynamics images [4]. Angiographs allow the experts to assess the arterial lesions by checking the condition of the coronary arteries and detecting the presence of stenoses.

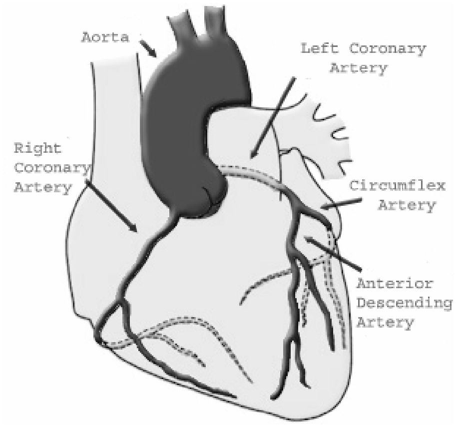

Figure 1. The coronary arteries

The specialist uses the qualitative analysis of the angiographs to establish a diagnosis based on the number of affected blood vessels and ramifications. This punctuation is an approximate value that does not consider the particular coronary anatomy and is subjected to a high level of variability [5]. An ideal system would allow the expert to determine which proportion of the coronary tree is distal to the significant stenoses (i.e. with a narrowing above 70 %), providing as such a risk punctuation or “score” that is directly related to the affected myocard tissue.

The initial hypothesis of the present work is that it is possible to develop a semiautomatic decision support system for the diagnosis of ischemic cardiopathies. The techniques for digital analysis and processing allow us to develop a reproducible and reliable procedure for automatic quantification, based on a segmentation process that implements a tracking system for the visualization of the artery profiles and the subsequent elaboration of measurements.

This objective method unifies the assessment criteria and as such makes it possible to compare patients with similar pathologies, have consultations both inside and outside the hospital, and use the data for the training of inexperienced professionals.

Materials and Methods

We work with DICOM images with a resolution of 512*512 bits and 8 bits per pixel for the grey level.

ISSN: 1727-1983 © 2005 IFMBE

The image has a noisy background with confusing visual indications and characteristics that are inherent to blood vessels: complex structure, dynamism, great variability, bidimensional and static projection of a moving structure, etc. These factors make it a very challenging environment.

The developed image processing technique consists of a semiautomatic phase of vasculature extraction, and a phase of vasculature analysis that quantifies the seriousness of the stenosis.

Vasculature extraction algorithm

In the course of a diagnosis, the extraction of the vasculature is an essential and critical step that presents a considerable complexity [6], since there exists no method to automatically segment any type of angiograph and to pursue the development of more precise, rapid and automatic techniques [7].

The characteristics of the angiograph images suggest an approach based on knowledge. The easiest way to exploit this knowledge is to concentrate the search on the proximity of a blood vessel and track its characteristics: elongated structures that are slightly darker than the background, slow variations in diameter and intensity, etc.

The developed segmentation algorithm is a technique for the “tracking” and extraction of characteristics. Starting from a seed point and an initial direction, the blood vessels are tracked and we obtain the points of their skeleton and edges in an extrapolation and structure that is updated in steps. This implies eight phases:

1. approximate detection of the edge points on the basis of the density information in a template
2. definition of the skeleton point as the average point of the edge points
3. classification of the pixels from the inside of the template, depending on whether they belong to the blood vessel
4. repositioning of the centre of the template in the last skeleton point:

$$p_{i+1} = \frac{1}{2}(e_1 + e_2) \quad (1)$$

$$d_{i,i+1} = p_{i+1} - p_i \quad (2)$$

$$w_{i+1} = \left\| e_1 + e_2 \right\|^2 \quad (3)$$

5. adaptation of the template size according to the local diameter of the blood vessel
6. automatic recognition of the ramification points
7. increase of the template size if necessary
8. finalisation of the tracking if the conditions are fulfilled

Figures 2 (a) and (b) show these phases for the i-th step and how the tracking process evolves in its successive steps and with the use of a circular template. Figure 3 shows a moment of that evolution in a real example.

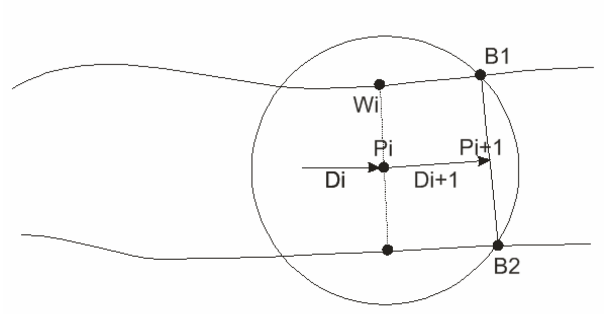

Figure 2 (a). Scheme of the tracking process in the i-th step.

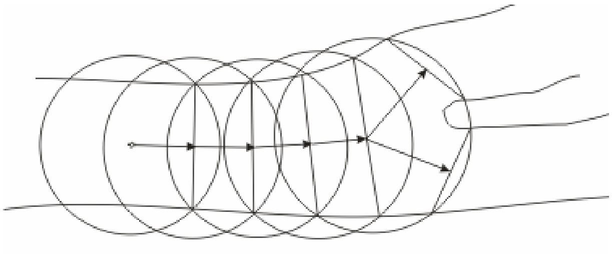

Figure 2 (b). Evolution of the tracking in the proximity of a bifurcation

Figure 3. Moment in the evolution of the tracking

Once the initial segmentation is finished, the tool’s rich interface allows us to continue the exploration in other undetected blood vessels, and to complete and correct the segmentation by hand. These characteristics, together with the possibility of varying several parameters of the method, allow the clinical expert to maintain a certain degree of control over the process.

Stenosis evaluation algorithm

If the expert is satisfied with the segmentation, he locates the stenoses in the segmented image and assesses the store of each stenosis and its total affection according to the relative positions. The interface allows the expert to guide the process by solving possible quantification errors that are mainly due to superpositions and the system's lack of knowledge concerning the model of the coronary tree.

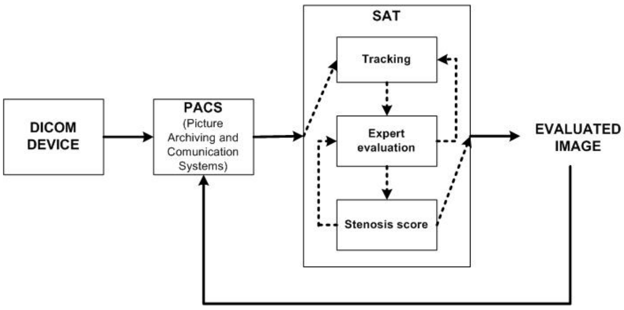

Figure 4. Software model of the SAT tool as integrating part of a medical image management system.

SAT Tool.

The user has access to the above techniques through a Stenosis Assessment Tool (SAT) that offers all types of functionalities.

This interface was developed with JAVA language so that it can easily be integrated into other systems such as the systems for the management of medical images [9], which dispose of web interfaces. Figure 4 shows how the tool is integrated into a PACS system with web interface.

Figure 5. Interface of SAT tool.

The tool was designed in collaboration with various cardiologists who are specialized in the analysis of hemodynamics images: we wanted to develop a solution that is adapted to their particular needs and complies with all the requirements concerning safety, efficiency, and usability.

The next section shows a series of images that illustrate the functioning of the SAT tool.

In Figure 5, we observe the general look of the interface that is presented to the user. The user starts by activating the segmentation algorithm and obtains results as seen in Figure 6. If he wants to see the results of the initial segmentation more clearly, he can move the scroll bar and change the superposition level of the segmented image (see following images).

Next, the image is manipulated by hand: false segments are deleted with an adaptable brush, and undetected sections are added and can be subjected to the algorithm. Figure 7 gives an example of such a manipulation.

Figure 6. Results of the initial segmentation

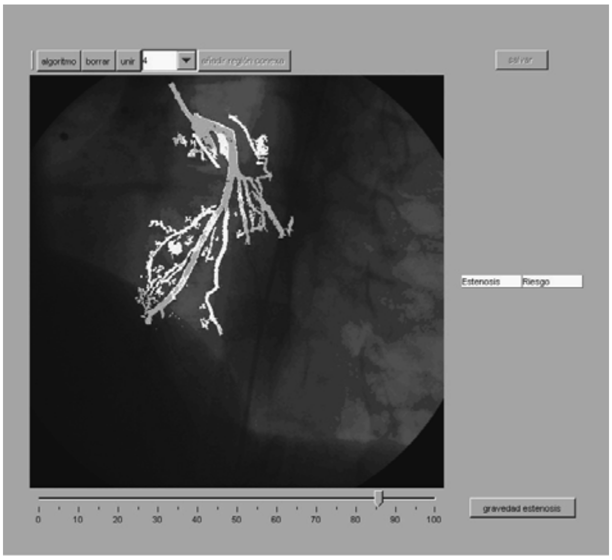

Figure 7. Manual correction of the segmentation results

If the expert is satisfied with the segmentation, he can execute the "score" algorithm, i.e. the evaluation of the stenosis. He marks a stenosis on the image (see Figure 8), and can then correct these initial results with the brush by separating the sections that were

ISSN: 1727-1983 © 2005 IFMBE

incorrectly classified as affected area. The evaluation is repeated, and the new results are shown in a new image (Figure 9).

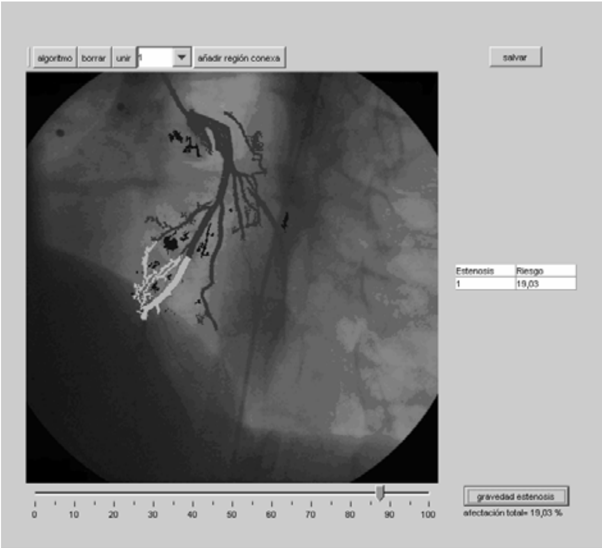

Figure 8. Calculation of the risk of the marked stenosis

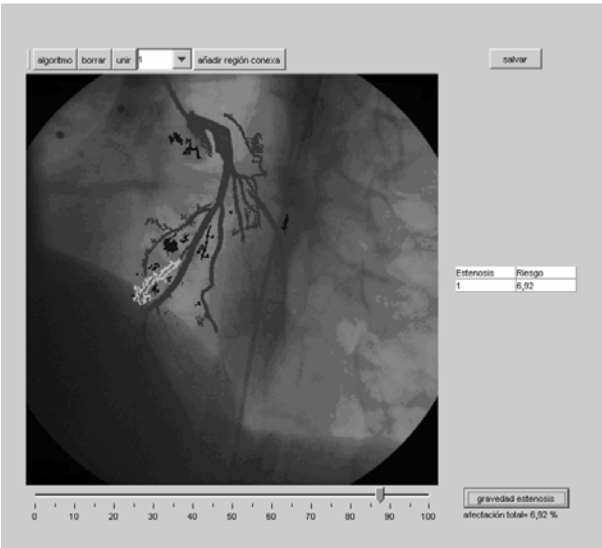

Figure 9. Repetition of the calculation of the stenosis risk on the corrected image

The user now marks a second stenosis, calculating both its seriousness and the total affection of all the present stenoses, as can be seen in Figure 10. When the expert decides to save the obtained results, the interface shows once again the initial segmented image and offers the possibility to carry out new valuations, possibly by a second expert.

Conclusions

Making use of only one image, the developed system semi-automatically detects the coronary vasculature using one plane (it's the type of device available in the hospitals of our region), with the intervention of the expert and the guidance of the application. It then establishes a quantification pattern of the effect of the coronary stenosis, by providing the risk level of the marked stenoses based on an estimation of the amount of affected myocardic tissue. The fact that the stenoses can be quantified as a whole is new but fundamental for the cardiologists who collaborated in the development of the system.

Figure 10. Calculation of the risk of a new stenosis and update of the total risk

The use of Java as working environment of the SAT application contributes to an object-oriented, extensible and portable software that can easily be integrated into web-oriented medical information systems, which manage the angiographic studies generated in hemodynamics units.

This system can be integrated into PACS systems and therefore presents characteristics that most of the currently used systems lack: storage of the results in the records of the patient, easy revision by the medical expert, remote access, etc.

We developed a simple, intuitive and automatic interface based on the web development paradigm, an environment that is well known among most hospital staff. Also, the system can be used for the improved instruction and training of new specialists, since it allows them to compare with already stored cases.

References

[1] RINGQVIST I., FISHER L.D., MOCK M., DAVIS K.B. ET AL (1983): 'Prognostic value of angiographic indices of coronary artery disease from the Coronary Artery Surgery Study (CASS)', Journal of Clinical Investigation, **71**, pp. 1854–66.

[2] VILLAR F., BANEGAS J.R., DONADO J., RODRIGUEZ F. (2003): 'Las enfermedades cardiovasculares y sus factores de riesgo en España: hechos y cifras', Informe de la Sociedad Española de Arteriosclerosis.

[3] (1997): 'La prevención de las enfermedades cardiovasculares: Declaración de Cataluña', Rev. Panam. Salud Publica, **2** (2), pp. 77-101.

[4] CHERRAK I., PAUL J.F., JAULENT M.C., CHATELLIER G., PLOUIN P.F., GAUX J.C. AND DEGOULET P. (1997): 'Automatic stenosis detection and quantification in renal arteriography', Proceedings of AMIA Annual Fall Symposium, pp. 66-70.

[5] CALIFF R.M., ARMSTRONG P.W., CARVER J.R., D'AGOSTINO R.B., STRAUSS W.E. (1996): 'Stratification of patients into high, medium and low risk subgroups for purposes of risk factor management', Journal of the American College of Cardiology, **27**, pp. 1007–19.

[6] KOSTAS H., EFSTRATIADIS S.N., MAGLAVERAS N., PAPPAS C., GOURASSAS J. AND LOURIDAS G. (1999): 'Model-Based Morphological Segmentation and Labeling of Coronary Angiogragrams', IEEE Transactions on Medical Imaging, **18** (10), pp, 1003-1015.

[7] KIRBAS C. AND QUEK F. (2004): 'A Review of Vessel Extraction Techniques and Algorithms', ACM Computing Surveys, **36** (2), pp. 81-121.

[8] O'BRIEN J.F., EZQUERRA N.F. (1994): 'Automated Segmentation of Coronary Vessels in Angiographic Image Sequences utilizing Temporal, Spatial and Structural Constraints', Visualization in Biomedical Computing, 1994.

[9] PEREIRA J., CASTRO A., CASTRO A., ARCAY B., PAZOS A. (2002): 'Construction of a System for the Access, Storage and Exploitation of Data and Medical Images Generated in Radiology Information Systems (RIS)', Medical Informatics and Internet in Medicine, 27 (3) , pp. 203-212.