AUTOMATIC UNDERSTANDING OF SELECTED DISEASES ON THE BASE OF STRUCTURAL ANALYSIS OF MEDICAL IMAGES

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ABSTRACT

The goal of this paper is a presentation of the possibilities of the application of syntactic methods to the recognition of the local stenoses of the lumen of coronary arteries, and to the detection of pathological signs in upper parts of ureter ducts and renal calyxes. An analysis of the correct morphology of these structures is possible thanks to the application of sequence and tree methods from the group of syntactic methods of pattern recognition. In the case of the analysis of coronary artery images, the main objective is a computer-aided early diagnosis of the different forms of cardiac ischemic diseases. In the analysis of kidney radiograms the main goal is the recognition of local irregularities in ureter lumens, and an examination of the morphology of renal pelvis and calyxes.

1. INTRODUCTION

The topic of this paper is a presentation of the possibilities of the application of sequence and tree methods from the group of syntactic methods of pattern recognition, to the description of morphological changes, and the analysis of the shape features of selected organs from the chest and the abdominal cavity, showed in X-ray images. In particular, we present new methods for the following computer-aided diagnosis: the recognition of morphological changes in coronary vessels, and the shape analysis of the upper parts of urinary tracts i.e. ureters and renal pelvises.

The recognition of changes in the case of the analysis of coronary artery images is extremely important from the point of view of the correct diagnosis of heart ischemic states, caused by the arteriosclerotic changes in vessels, which lead to local stenoses of coronary arteries, and which in consequence lead to cardiac ischemic diseases. Such a disease may appear in the form of stable or unstable angina pectoris, or heart infarct. The aim of analyzing coronary artery roentgenograms is thus the detection of local stenoses of coronary artery lumen, and in particular so-called essential stenoses, that is stenoses which exceed 50%, and occur in the trunk of the left coronary artery; and stenoses over 70% in other segments of coronary vessels. An example of a coronary artery with stenosis is presented in Fig. 1A.

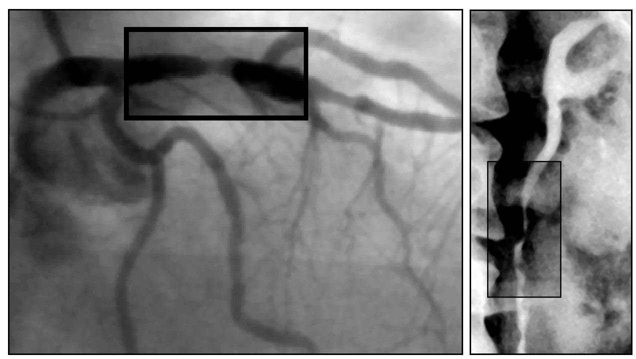

Fig. 1. Images showing pathological stenoses: **A)** image of coronary artery with stenosis; **B)** image of left renal pelvis with stenosed ureter

In the case of kidney radiogram analysis, the main goal is the recognition of local stenoses or dilatations of upper parts of the ureters (Fig. 1B), and an attempt at the diagnosis of regularity of the renal pelvis, and renal calyx morphology. These symptoms can point to the existence of renal stones, or of deposits causing urinary tract obstruction, which lead to such diseases as acute uremia, or hydronephrosis.

For a proper diagnosis of the above mentioned changes, and for a verification of how advanced their level, an attributed context-free grammar of type LR (1) and a tree grammar of type EDT [1] have been proposed. These methods have been applied to detect changes in the width of different structures, visible in graphs. These graphs are obtained thanks to applying at the image preprocessing stage, a straightening transformation, which allows the production graphs of straightened structures, while preserving the morphological changes occurring in them.

The main advantage of using context-free grammars is the possibility of detecting on obtained width profiles both concentric stenoses, revealed on a regular-cross section by the monotonous stenosis of the whole lumen, as well as eccentric stenoses revealed only on one side of the vessel. This property is especially useful for coronary artery diagnosis, because it permits the recognition of whether the detected symptom is characteristic of stable angina pectoris in the case of concentric stenosis diagnosis, or unstable angina pectoris when eccentric stenosis is revealed.

2. PREPROCESSING OPERATIONS OF MEDICAL IMAGES

Before coming to the recognition of the changes in question, it is necessary to preserve the sequence of operations, which are included in the image preprocessing. The goal of this analysis is obtaining width graphs, which show the pathological changes occurring in these structures.

During the initial analysis of the tested pictures, the following operations are executed: segmentation and skeletonization of the research structures [2], removing potential bifurcations, which can occur in the skeleton of the investigated structure [2], application of a straightening transformation [3]. The graphs obtained are the starting point in the recognition of morphological changes by using the context-free grammars suggested by the authors.

3. SYNTACTIC ANALYSIS AND DETECTING OF CORONARY ARTERIES STENOSES

The detection of changes occurring in the form of different kinds of lumen stenoses in coronary arteries was carried out on width graphs obtained during the preprocessing of coronary artery angiograms. These graphs show the straightened profiles of investigated coronary vessels. For a proper analysis and recognition of pathological stenoses the attributed grammar was suggested. It permits us to define all the potential shapes of expected morphological changes. A definition of this class of grammars can be find in papers [1].

For a proper description of the original components in the images, which fully permit us to create a linguistic description of changes, the obtained profile graphs of coronary arteries are submitted to a linear approximation method [4]. As a result of this operation, every investigated graph obtains a representation in the form of an approximating segments sequence, which is next inputted to the succeeding terminal symbols which create the new linguistic representation. This representation sets up the input information to the syntax analyzer, which is based on the grammar prepared by the authors. Such an analyzer creates a proper program for recognizing changes in the coronary artery lumen.

For recognition of the different kind of stenosis shapes, the following attributed grammar is suggested:

$G_{CA} = (V_N, V_T, SP, STS)$ where V_N - set of non-terminal symbols, V_T - set of terminal symbols, SP - set of production, STS - starting symbol of grammar.

V_N = {SYMPTOM, STENOSIS, H, V, NV}

V_T = {h, v, nv, λ}

for $h \in (-10°, 10°)$, $v \in (11°, 90°)$, $nv \in (-11°, -90°)$

STS = SYMPTOM

SP:

1. SYMPTOM → STENOSIS Symptom=Stenosis
2. STENOSIS → NV H V
3. V → v | v V $w_{sym} := w_{sym} + w_v$; $h_{sym} := h_{sym} + h_v$
4. NV → nv | nv NV $w_{sym} := w_{sym} + w_{nv}$; $h_{sym} := h_{sym} + h_{nv}$
5. H → h H | λ $w_{sym} := w_{sym} + w_h$; $h_{sym} := h_{sym} + h_h$

In the presented grammar the second of the suggested productions defines the potential shapes of the lumen of coronary vessels stenoses; the succeeding steps in this grammar the resulting specific linguistic formula, characterize the descending and the ascending part of the analyzed stenosis, and the last of the productions defines the horizontal segment, which can appear between both parts of the vessel. Semantic variables h_e and w_e determine the height and length of the terminal segment with label e. They have an auxiliary meaning when the diagnosis is formed and next presented to the physician. These attributes are used to determine the numerical parameters of the detected stenosis, which allows us to characterize the degree of lumen stenosis of the coronary artery as a percentage, which has an essential meaning for the diagnosis of the state of a patient health.

4. SYNTACTIC ANALYSIS AND THE DETECTION OF URETER STENOSES

Detection of morphological changes in the form of stenoses and dilatations of ureters is undertaken using the following attributed grammar: $G_u = (V_N, V_T, SP, STS)$ where V_N = {SYMPTOM, STENOSIS, DILATATION, H, V, NV}

V_T = {h, v, nv}

for $h \in (-8°, 8°)$, $v \in (9°, 180°)$, $nv \in (-9°, -180°)$

STS = SYMPTOM

SP:

1. SYMPTOM → STENOSIS Symptom=Stenosis
2. SYMPTOM → DILATATION Symptom=Dilatation
3. STENOSIS → NV H V | NV V | NV H
4. DILATATION → V H NV | V NV | V H
5. V → v | v V $w_{sym} := w_{sym} + w_v$; $h_{sym} := h_{sym} + h_v$
6. NV → nv | nv NV $w_{sym} := w_{sym} + w_{nv}$; $h_{sym} := h_{sym} + h_{nv}$
7. H → h | h H $w_{sym} := w_{sym} + w_h$; $h_{sym} := h_{sym} + h_h$

This grammar permits us to detect different forms of stenosis and dilatation, which characterize the different disease units. Using attributes as before permits us to calculate the numerical parameters of detected morphological change.

5. TREE GRAMMAR APPLICATION IN THE ANALYSIS OF RENAL PELVIS SHAPE

As tree, methods of syntactical image recognition are generally designed for the analysis of slightly more complex objects in the image, in the case of nephrogram analysis these methods are used to check regularities of renal pelvis and calyx morphology. Although these structures are characterized by unusual shape variation, it is possible to distinguish certain common features which characterize all proper structures, using the number of smaller and bigger calyxes revealed in the renal sinus. Only 2 or 3 bigger calyxes usually drain into a normal pelvis and they are formed by drained into smaller calyxes numbering from 8 to 10. Smaller calyxes end in concave renal papillae, which are the tops of renal pyramids. To analysis these structures we will suggest an expansive tree grammar defined with the aim of analyzing the skeleton morphology of investigated renal pelvises and renal calyxes. The obtained skeleton is analyzed in such a manner that the first point of skeleton bifurcation is the starting point of the skeletons of bigger calyxes, therefore specifying the number of branches which have begun there allows us to calculate the number of bigger calyxes. By determining the range of branches in each bigger calyx, we can calculate the number of smaller calyxes leading from it. In smaller calyxes an analysis of end points in a skeleton allows us to ascertain whether there are branches in further degree. This means, that the renal papillae is not concave into the calyx, but has a convex shape towards the renal pyramids. This happens in the case of hydronephrosis, or is caused by cysts in the case of a tumor process. A tree grammar describing the correct skeletons of renal pelvises and renal calyxes is defined in such a way that root of the tree is defined by the location bifurcation in the bigger calyxes. Next, its consequents are determined by branch points of the second degree, which is the beginning of the smaller calyxes. The last layer of vertices is defined by branch points of the third degree, that is branches which appear in a case when the renal papillae has a concave shape.

To diagnose morphological changes in renal pelvises the following tree grammar was used:

$$G_{edt}=(\Sigma, \Gamma, r, P, Z)$$

where $\Sigma = \Sigma_N \cup \Sigma_T$ is a set of terminal and non-terminal vertex labels, r is a function which assigns to the tree vertex the number of its consequents, Z is a finite set of starting trees, Γ - is a set of edge labels, and P- is a set of production.

Σ_T = {pelvis, calyx_b, calyx_s ,l}
Σ_N = {RENAL_PELVIS, B, C}
Γ = {x, y, z}
for $y \in (-30°, 30°)$, $x \in (30°, 180°)$, $z \in (-30°, -180°)$
Z = {RENAL_PELVIS}
P:

1. RENAL_PELVIS → pelvis (xB yB zB) | pelvis (xB yB)
2. RENAL_PELVIS → pelvis (yB zB) | pelvis (xB zB)
3. B → calyx_b (xC yC zC)
4. B → calyx_b (xC yC) | calyx_b (xC zC) | calyx_b (yC zC)
5. C → calyx_s (xl) | calyx_s (yl) | calyx_s (zl)
6. C → calyx_s (xl yl) | calyx_s (xl zl) | calyx_s (yl zl)

The first group of production defines the different kinds of normal renal pelvis i.e. having two or three smaller calyxes. The succeeding productions define the form of bigger calyxes formed from two or more smaller calyxes. The last group defines the proper form of renal papillae, which obtains a fork form during the skeletonization, which means it finishes with short branches, which arise only when it is concave to the interior of a smaller calyx. Convex forms during skeletonization are thinned to the line without end branches, which results from the properties of skeletonization algorithms.

6. RECOGNITION RESULTS OBTAINED BY USING CONTEXT-FREE GRAMMAR

Thanks to the application of the presented context-free grammars it is possible quite precisely to detect different kinds of irregularities in the form of stenoses, or a dilatation of investigated structures.

The detection of irregularities appearing in the set of test data is carried out by syntax analyzers, generated on the basis of the formal description of grammars presented in this paper, and with application of YACC grammars compiler. The analyzing program formed in this way was tested during a series of tests whose aim was recognition of stenoses on several representatively selected images of coronary arteries. Analysis of the morphological changes in upper urinary tracts was carried out on the basis of a set of a dozen or so urograms and kidney reontgenograms containing images which show both congenital changes in renal pelvises and ureter morphology, and the acquired changes which show the existence of a disease process.

For the presented tree grammar an automaton with output above the set of vertex labels was constructed to serve the syntactical analysis of the tree languages defined by these types of grammars. The results obtained thanks to the application of the characterized methods, confirm the immense of syntactical methods in the diagnosis of cardiac ischemic diseases.

In Fig. 2 we present an examples which show recognition of the changes in question for coronary artery

(Fig. 2A) and urinary tract (Fig 2B) images.
The recognized symptoms are marked by the bold line.

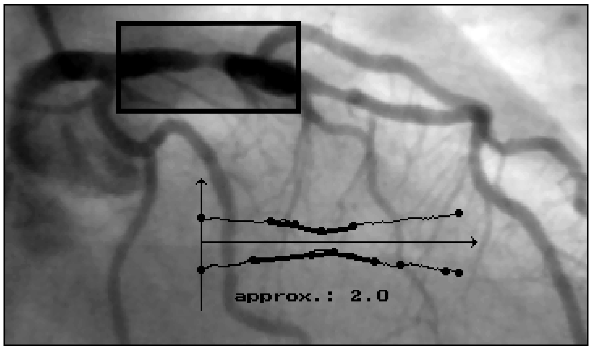

Fig. 2A. Result of disease symptom diagnosis using syntactical methods of pattern recognition in case of coronary artery

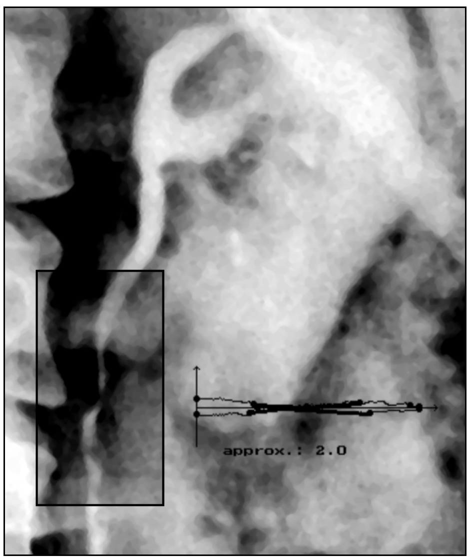

Fig. 2B. Result of disease symptom diagnosis using syntactical methods of pattern recognition in case of upper part of the ureter duct

7. CONCLUSIONS

The research carried out by the authors into the possibilities of recognizing pathological changes in the morphology of coronary arteries and renal pelvises, along with upper parts of the ureter have confirmed the universality of application of the mathematical linguistic method in the recognition and analysis of morphological changes in medical images. The great efficiency of the presented algorithms makes these methods an unusually useful tool from a practical point of view in the domain of scientific engineering, allowing us to enhance and recognize essential diagnostic features in the analysis of medical images.

So far these methods have been used in earlier authors' papers to detect morphological changes in main pancreatic ducts [2, 4]. This paper proves that the presented methods also have an application in cardiology and nephrology. However, due to the small amount of test data, the improvement of these methods is an ongoing process and the necessity of further research concerns mainly the recognition of the pathology of renal pelvises by means of tree grammar analysis. To date, the results of such analysis undertaken on several representative images are very promising, and suggest a high efficiency of recognition for the analysis of a large amount of test data.

The possibilities for the wide use of these kinds of methods in medical image analysis mean that they can also play an important role in archiving systems and the transmission of medical images (Picture Archiving and Communication Systems - PACS) especially in the form of modules which aid the recognition and diagnosis of disease changes.

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