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Syntactic reasoning and pattern recognition for analysis of coronary artery images

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Abstract

This paper presents a new approach to the application of structural pattern recognition methods for image understanding, based on content analysis and knowledge discovery performed on medical images. This presents in particular computer analysis and recognition of local stenoses of the coronary arteries lumen. These stenoses are the result of the appearance of arteriosclerosis plaques, which in consequence lead to different forms of ischemic cardiovascular diseases. Such diseases may be seen in the form of stable or unstable disturbances of heart rhythm or infarctions. Analysis of the correct morphology of these arteries lumen is possible with the application of the syntactic analysis and pattern recognition methods, in particular with the attributed grammar of LALR type. In the paper, we shall describe all stages of analysis and understanding of images in the context of obtained features, and we shall also present the proper algorithm of syntactic reasoning based on the acquired knowledge.

Keywords: Image understanding; Knowledge discovery; Syntactic pattern recognition; Medical imaging; Artificial intelligence

1. Introduction

This paper presents new possibilities of computer-aided diagnosis and recognition of coronary vessel lesions with the application of syntactic image recognition methods.

Application of these methods allow one to obtain a far deeper analysis, than the simple recognition of pathologic lesions would; and leads to describing the semantic content of analysed images. Such reasoning imitates the process understanding the significance of the recognised pathology on a medical image. This also has a particular importance not only

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for the correctness of undertaking diagnosis, but it also constitutes a new technique of knowledge determination in the area of knowledge discovery. Based on the gained diagnostic information, these methods may also be helpful in constructing intelligent visual and information systems designed for medical robots. Such systems base their operation on syntactic reasoning with the use of grammars. This allows one to adjust their operation well to the natural variation of patterns characteristic for biological structures of organs—both the correct ones and those with pathological lesions.

The paper shows that the proposed methods enable one of the intelligent pattern of understanding, owing to which, it is possible to recognise efficiently pathological lesions of diseases such as myocardial ischaemia. The innovative features of the approach consist of a possibility to conduct, with the use of proposed algorithms, a much deeper analysis directed at defining a semantic content of the pattern analysed. This in turn is an attempt at implementing computer systems understanding patterns. Those systems may in the future become an integral part of robots supporting surgeries or a part of medical information systems widely supporting medical diagnosis or the processes of specialist training of highly qualified experts.

The linguistic methods of analysis of the medical images content based on grammatical reasoning were used by other researchers, both in order to perform simple semantic reasoning relating to their content [8,9] and to create a description of the morphology of important shapes, e.g. the ECG course analysis [21] and the description of selected sequences in DNA chains [5]. Those methods served also to support the sign language for the deaf and the mute [13] as well as eye movement analysis in ophthalmologic examinations [6]. Structural analysis, however, has not been used to support the diagnosis of the ischaemic heart disease based on coronography images.

2. Medical problem domain—the cardiac ischemic states

Recognising lesions visualised on coronary vessels images is very important from the point of view of correct diagnosis of heart ischaemic disease caused by atherosclerosis lesions of coronary vessels, which give rise to artery lumen stricture. This, in consequence, can lead to heart ischaemic disease. The heart ischaemic disease can manifest itself in the form of stable or unstable angina or as myocardial infraction.

Methods described in this paper have the objective to analyse and diagnose stenoses of coronary arteries, in particular the so-called significant stenoses that is the stenoses of the coronary lumen exceeding 50% occurring in the trunk of the left coronary artery as well as stenoses exceeding 70% in the remaining sections of coronary vessels. The importance of diagnosis of those morphological lesions can be demonstrated by the fact that closing the lumen of one of left coronary artery trunks, e.g. the anterior interventricular artery can constitute a considerable life threat due to the fact that it leads to ischaemia of more than 50% of the left ventrical cardiac muscle.

The main advantage of the use of context-free grammars as compared to the methods of analysis proposed by other researchers [11,18] is a possibility to diagnose—as a result of initial image processing—the profiles of the examined artery width, both concentric stenoses seen on a cross-section as a uniform stricture of the whole lumen as well as eccentric stenoses occurring only on one vascular wall. This fact is important from the point of view of diagnosis, since it allows one to recognise if the discovered symptom is characteristic for a stable disturbance of heart rhythm (the case of diagnosed concentric stricture) or for unstable angina (in the case in which an eccentric stenosis is discovered) [7,16].

3. Medical data collection and understanding

Recognition of cardiac ischemic lesions was conducted on static images showing coronary vessels obtained during coronarographic examinations. For the purpose of evaluation of the efficiency of the proposed methods and in order to define correctly the grammar recognising artery stenosis, we used the set of images obtained during the specialist examination of 30 patients with distinct ischemic symptoms. All cases were qualified for coronary artery bypass operation or balloon catheterisation treatment. All cases obtained in the course of diagnostic coronography examinations had stenosis exceeding 70% of lumen in at least one of the coronary vessels shown. On the other hand, the stenoses, which occurred as a result of atherosclerosis lamella in the majority of cases, were located in the proximal segments of the analysed arteries. For the test set of images obtained from a group of 30 patients, the percentage distribution of data depending on the number of vessels with stenosis at one patient and the location of atherosclerosis stenoses are following:

1. Number of visible arteries with stenoses on the image: one vessel (95%) and two vessels (5%).
2. Location of vessel stenosis: proximal (92%), distal (8%).

Moreover, in the majority of cases, the visible stenoses were concentric and did not exceed 10 mm in length. For the test procedure, we selected also images without visible thromboses and without ramifications branching out from the stenoses.

During examinations for each patient, a set of DICOM sequences [18] showing both contrasted arteries in various planes and projections were obtained. Such images are stored in resolution 512×512 pixels with the 8-bit grey scale. For recognition of interested symptoms from owned sequences of images, we selected representative images precisely showing each kind of stenoses; images were stored as raster images in the TIFF format. Examples of cardiac arteries with stenoses are shown in Fig. 1.

Before coming to the recognition of the changes, it is necessary to preserve the sequence of operations, which are included in the image pre-processing. The goal of this analysis is to obtain width graphs, which show the pathological changes occurring in these arteries.

4. Preparation of the cardiac images

Obtaining width diagrams of the analysed vessels in such a way that they show both concentric and eccentric stenoses is possible owing to the use—at an early stage of initial

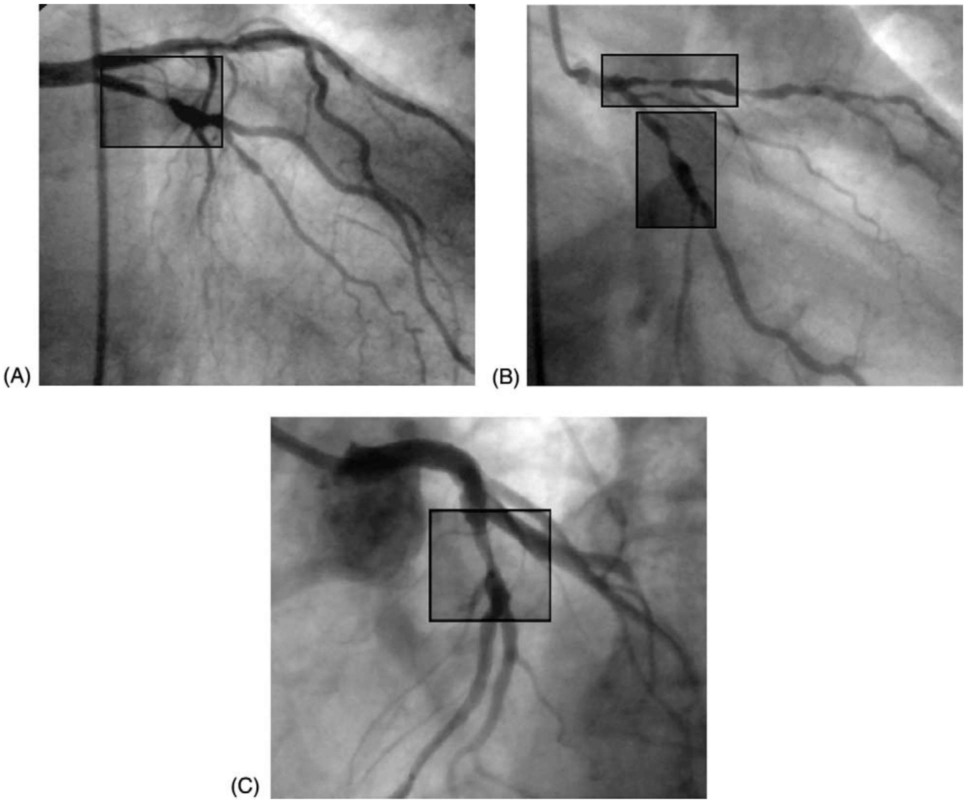

Fig. 1. (A–C) Coronographic images of coronary arteries with stenoses.

image processing—an approach to marking the central line and producing width diagrams differing from the ones proposed so far [11]. Research conducted have demonstrated that in order to obtain the central line, much better results can be obtained with the use of the method of skeletonisation of arteries with the Pavlidis classic algorithm [16] rather than the application of the morphological operation of erosion of the binarised vessel (used until now) [3,4,10] or determining the line manually by the operator. Thus, the obtained central line is cut to a lesser degree in the course of processing it at its ends and it occupies the very central position. In order to obtain width diagrams, a specialised straightening transformation algorithm described in paper [17] has been used; it allows to obtain width diagrams of the analysed vessels together with morphological lesions occurring in them and correct ramification of the diagnosed arteries.

Initial analysis of the images from coronarographic examinations is composed of the following operations:

- Segmentation and skeletonisation of the examined coronary arteries. To segment and recognise edges, we can use the method of subtractive connection of original images with images subject to high-pass filtration [1,2,11]. Next, the result of subtraction is subject to methods of gradient analysis used to discover edges. The method of high-pass temporal filtering is equally effective [10,11]. This filtration is executed in a situation, in which, in order to separate the looked-for structure we use the whole sequence of images obtained in the course of one operation of coronary arteries contrasting. This type of filtration allows one to isolate the searched structure based on local changes of contrast appearing at shifting from one image from a given section to another one [18]. Another possible approach is the use of a specialist threshold algorithm for segmenting described in paper [12].

- Application of a straightening transformation transforming the external contour of the examined artery from a two-dimensional space to a one-dimensional diagram showing the profile of the straightened coronary artery. Details of actions and advantages resulting from the use of this transformation have been presented in paper [14,17], while diagrams used with its help constitute a starting point to diagnose morphological lesions with the use of the context-free grammar proposed by the authors.

Fig. 2 shows examples of width profiles obtained for coronary arteries.

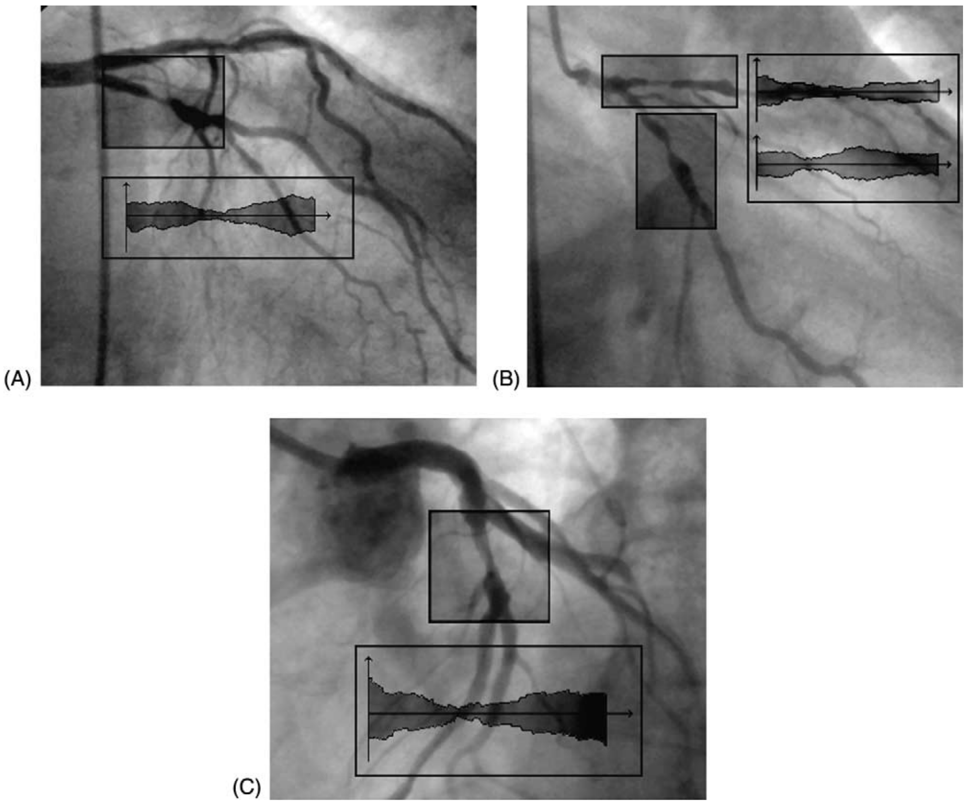

Fig. 2. (A–C) Coronary artery images with visible width profiles of sections with stenoses.

In order to recognise and define the degree of advancement of those lesions correctly, a context-free attributed grammar of the look-ahead LR(1)-type has been proposed. This grammar allows to diagnose this type of irregularity in an efficient way on the X-ray images obtained in the course of coronographic examinations.

5. Data mining and structural description of stenosis of coronary artery lumen

Diagnosing morphological lesions taking the form of various types of coronary artery lumen stenoses has been conducted on width diagrams obtained in the course of initial processing of coronary angiograms. Those diagrams show the profiles of the examined coronary vessels; attributed grammar allowing one to define all potential shapes of the expected morphological lesions has been proposed for their analysis and recognition.

The presented grammar was defined as a result of matching of their deriving rules to the test set of images consisting from a few dozens of images with distinctly visible stenosed coronary vessels.

Attributed grammars belong to a wider group of syntactic methods of image recognition; they are widely used in various tasks connected with artificial intelligence. So far, however, they were not used to analyse morphological lesions of coronary arteries. Definition of this class of grammars can be the following:

Definition 1 Context-free grammar $G = (V_N, V_T, SP, STS)$ is a grammar of the type LR(k) (for $k \geq 0$) of for every derivation step in the form of:

$$STS \overset{R}{\Rightarrow} \mu A \omega \Rightarrow \mu \chi \omega; \quad \mu \in V^*, \ \omega \in {V_T}^*, \ A \rightarrow \chi \in SP$$

$$STS \overset{R}{\Rightarrow} \mu' B \omega' \Rightarrow \mu' \gamma \omega'; \quad \mu' \in V^*, \ \omega' \in {V_T}^*, \ B \rightarrow \gamma \in SP$$

condition $(|\mu\chi| + k)$: $\mu\chi\omega = (|\mu'\gamma| + k)$: $\mu'\gamma\omega'$ implies that $\mu = \mu'$, $A = B$, and $\chi = \gamma$, where $\Rightarrow^R$ stands for a right-hand argument (right-hand derivation or the introductory step) in the grammar, that is at every step, the new inscription is derived from the extreme right non-terminal symbol.

$$V = V_T \cup V_N,$$

$$V^* = \{\mu : \mu = x_1 x_2 \ldots x_n, n \geq 1, x_i \in V \text{ for } i = 1, \ldots, n\} \cup \{\lambda\} (\lambda \text{ is an empty symbol})$$

$${V_T}^* = \{\omega : \omega = y_1 y_2 \ldots y_m,$$

$$m \geq 1, y_1 \in V_T \text{ for } i = 1, \ldots, m\} \cup \{\lambda\}, \mathrm{k:w} = \begin{cases} w, \text{when } |w| < k \\ \alpha, \text{when } w = \alpha\gamma \text{ and } |\alpha| = k \end{cases}$$

Those grammars belong to the most universal ones; they enable a structural analysis of almost all language sequences generated by defined deriving rules. Those grammars are analysed in a determinist way by reduction automates of the LR(1)-type. Definition of this type of automates is the following:

Definition 2 Automate of the LR(1)-class (or LR(1)-automate) for a G grammar is the following sequence:

$$\mathrm{LRA}(G) = (Q, V_\mathrm{n}, V_\mathrm{t}, \mathrm{SP}, q_0, \mathrm{next}, \mathrm{reduce})$$

where Q is a finite, non-empty set of states of the automate; V_n and V_t are finite sets of non-terminal and terminal symbols; SP production set and $q_0 \in Q$ is the initial state of the automate.

The function of the *next* state is defined in the following way:

$$\mathrm{next} : Q \times (V_\mathrm{n} \cup V_\mathrm{t} \cup \{\$\})^* \rightarrow Q \cup \{\mathrm{stop}\}$$

and it meets the following conditions (symbol $ is the limiter of the input sequence):

1. $\mathrm{next}(q, \lambda) = q$
2. $\mathrm{next}(q, \alpha x) = \mathrm{next}(\mathrm{next}(q, \alpha), x)$

The reduce function is defined as: reduce: $Q \times (V_\mathrm{n} \cup V_\mathrm{t} \cup \{\$\})^* \rightarrow 2^{\mathrm{SP}}$

Automate of the LR(1)-type operates in such a way that it analyses the input sequence from the left-hand to the right-hand side by reading its successive elements; at the output, it generates the opposite of the right-hand derivation of the input sequence. In the course of analysis, no more than one input symbol is examined at every step.

Automates of the LR(1)-type belong to a group of reduction analysers table-steered by the so-called parser steering table. In reality, this means that parsers of the LR(1)-class are implemented in the software with the use of a table describing the successive states and numbers of reducing productions. The operation of the automate is determined by two functions describing the current state of the analyser. Those functions are the *action procedure* and the *goto* function. Definitions of those two functions can be found in paper [20].

The general methodology of application of syntactic pattern recognition for the creation of a perceptual description for the analysed structures and pathological signs is the following: starting from defining of simple shape elements, we build the general grammar description of the considered organ. Such descriptions, in the form of sequences of terminal symbols belong to the languages generated by the introduced grammar. The main analysis and recognition of pathological signs are based on parsing algorithms which analyse input sequences and reduce them to one of the known categories.

In order to define correctly the primitive constituents in the image, which will allow one to create the linguistic description of the looked-for lesions fully, the obtained diagrams presenting profiles of coronary artery profiles are subject to line approximation with the method used by the authors earlier in their other research tasks [15] and known in the scientific literature as fast polygonal approximation. As a result of this operation, every examined diagram obtains its own representation in the form of a sequence of approximating sections. Those sections are then allocated to successive terminal symbols producing a new linguistic representation. This representation constitutes the input information to the syntax analyser based on the grammar prepared and presented below. Syntax analyser constitutes the right software will recognise the looked-for lesions of coronary artery lumen.

In order to recognise various shapes of stenoses, we propose the following attributed grammar:

$$G_{CA} = (V_N, V_T, SP, STP)$$

where V_N is the set of non-terminal symbols, V_T the set of terminal symbols, SP the production set, STS the grammar start symbol.

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

$$V_T = \{h, v, nv\} \text{ for } h \in (-10^\circ, 10^\circ), v \in (11^\circ, 90^\circ), nv \in (-11^\circ, -90^\circ)$$

STS=SYMPTOM

SP:

1. SYMPTOM → STENOSIS	SYMPTOM := STENOSIS
2. STENOSIS → NV H V	
3. STENOSIS → NV V|NV H	
4. $V \rightarrow v \| V\ v$	$w_{sym} := w_{sym} + w_{nv}$; $h_{sym} := h_{sym} + h_{nv}$
5. NV → nv|NV nv	$w_{sym} := w_{sym} + w_{v}$; $h_{sym} := h_{sym} + h_{v}$
6. $H \rightarrow h \| H\ h$	$w_{sym} := w_{sym} + w_{h}$; $h_{sym} := h_{sym} + h_{h}$

In this grammar, the second and third of the proposed productions defines potential shapes of coronary vessel lumen stenoses. Successive steps introducing a defined linguistic rule into this grammar define the shape of arms of the descending and ascending parts of the analysed stenosis.

The semantic action in the first production (Symptom := Stenosis) means that the syntactic analyser has analysed the input sequence correctly and that it discovered a vessel stenosis in it.

Semantic variables h_e and w_e specify the altitude and length of the terminal section labelled e. They have an auxiliary role in making the diagnosis more specific and they allow to define in percentage the degree of the coronary vessel lumen stenosis.

Those variables are used by the analyser at the time of reduction of syntactic rules corresponding to them. Those reductions are executed by the parser one by one until the grammar start symbol is obtained. For correctly defined descriptions of artery stenoses, such an action leads in consequence to an identification of the stenosis and to defining its numeric parameters allowing one to make a precise diagnosis and to consider the direction of further therapy.

The simplicity of this presented grammar results mainly from the considerable generation power of context-free grammars when applied to analyse and recognise medical images.

6. Evaluation of the discovered knowledge (recognition results obtained by structural analyser)

Owing to the application of the here-presented context-free grammar, it is possible to diagnose with great precision the size of coronary artery stenoses. In the case of syntactic analysis, we are dealing with a situation in which the recognising software supplies practically all information relating to the morphological incorrectness of the examined arteries.

Diagnosing incorrectness occurring in the set of test data with records of examinations of a few dozen patients (more than a dozen of DICOM sequences in various projections for every patient) has been conducted by the syntax analysed, generated for the here-presented grammar on the basis of its formal record. Sequences of the syntactic analyser states have been obtained with the application of YACC compiler [15]. This sequence produces a parser steering table, used to recognise the looked-for symptoms. A complete table of parser states of the LALR(1)-type obtained for grammar defining stenoses on external contours of the coronary arteries have been shown in Table 1. To simplify the record and improve legibility, semantic actions computing the altitude and length of the recognised symptoms have been removed.

Table 1 presenting a table of steering parsers specifies all states of the implemented syntax analyser, together with a summary of the number of symbols generated and the states of the automate. From the practical point of view, the most important information here is the report on the number of conflicts of the shift/reduce and the reduce/reduce type, which can occur here. The occurrence of such conflicts is a sign of an ambiguity of the grammar defined and it means that one has gone beyond the LALR(1) grammar. This gives rise to a need to re-define syntactic rules in such a way so as to enable the generation of a fully deterministic parser recognising the analysed changes.

In order to facilitate the interpretation of the syntax analyser input states presented here, we shall explain the following:

1. Successive automate states are labelled by means of a key word ‘state no’.
2. In every state in which there is an analyser, there are definitions of both actions, which a parser can perform in a given state as well as it has a description of the syntactic rule analysed in this state. Symbol ‘_’ used in those rules is applied to specify which symbol has already been read by the analyser (symbol before the ‘_’ sign) and in the course of the current analysis of a given rule as well as what will be the next symbol (symbol after the ‘_’ sign).
3. In every state further parser, actions are defined depending on the terminal symbol seen at the input. Those actions are described in the following way:

   ◦ Action of reading the input *shift* symbol recoded with sequences in the form of: **terminal_symbol** *shift* **next_state**.

     This means that in its current state, the analyser has a token defined by a **terminal_symbol** at its input. Therefore, the analyser makes a shift locating it at the top of the stack and passes on to the next state defined by the **next_state**.

   ◦ *Reduce* action noted by a sequence in the form of: . reduce **number_production**.

     This means that in the current state at the top of the stack is the right side of the production numbered **number_production**. As a result, the right side of the production is replaced by its left side.

   ◦ Action of transition to the new state *goto* noted by a sequence in the form of: **nonterminal_symbol** *goto* **next_state**.

     This means that after the execution of reduction at the top of the stack is not a **nonterminal_symbol** but the current state of the automate. It is, therefore, necessary

Table 1
Table of syntax analyser states for the grammar describing coronary artery lesions

```
State 0
    $accept: _SYMPTOM      $end
    nv shift 4
    . error
    SYMPTOM goto 1
    STENOSIS goto 2
    NV goto 3
State 1
    $accept:      SYMPTOM_$end
    $end accept
    . error
State 2
    SYMPTOM: STENOSIS_ (1)
    . reduce 1
State 3
    STENOSIS: NV_H V
    STENOSIS: NV_V
    STENOSIS: NV_H
    NV: NV_nv
    h shift 8
    v shift 9
    nv shift 7
    . error
    H goto 5
    V goto 6
State 4
    NV: nv_ (8)
    . reduce 8
State 5
    STENOSIS: NV H_V
    STENOSIS: NV H_ (4)
    H: H_h
    h shift 11
    v shift 9
    . reduce 4
    V goto 10
State 6
    STENOSIS: NV V_ (3)
    V: V_v
    v shift 12
    . reduce 3
State 7
    NV: NV nv_ (7)
    . reduce 7
State 8
    H: h_ (6)
    . reduce 6
State 9
    V: v_ (10)
    . reduce 10
```

Table 1 (*Continued*)

```
State 10
    STENOSIS: NV H V_ (2)
    V: V_v
    v shift 12
    . reduce 2
State 11
    H: H h_ (5)
    . reduce 5
State 12
    V: V v_ (9)
    . reduce 9
5/127 terminals, 5/200 nonterminals
11/400 grammar rules, 13/600 states
0 shift/reduce, 0 reduce/reduce conflicts reported
8/0 working sets used
Memory: states, etc. 125/0, parser 5200/5
8/450 distinct lookahead sets
0 extra closures
8 shift entries, 1 exceptions
6 goto entries
0 entries saved by goto default
Optimizer space used: input 25/0, output 5200/13
13 table entries, 0 zero
Maximum spread: 259, maximum offset: 259
```

for the automate to go to a new state defined as **next_state** and to locate it at the top of the stack.

- Action of acceptance of the input sequence, *accept*. This action means that the whole input sequence has been read and that it belongs to the language generated by the grammar. This action is performed when the input symbol is the sign of the end of the input sequence ($end in the state table).
- *Error* detection action, which means that analyser, cannot conduct further analysis in accordance with syntactic rules. This situation takes place when after the read input symbol the next symbol seen cannot form with it a correct sequence describing the recognised object.

The analysing programme generated using YACC compiler has been tested on a number of test data samples. The image set of test data, which has been used in order to determine in percentage the efficiency of a correct recognition of the size of stenoses included 55 different coronary arteries images obtained for patients with heart disease. In this set, we considered image sequences of patients previously analysed at the stage of the grammar construction and the recognising analyser. In order to avoid analysing identical images, we selected separate images occurring a number of positions before or after the ones used originally. The remaining images in the test data have been obtained for a new group of patients (25 persons), including five persons who have previously undergone the angioplasty and in whose cases a restenosis of the previously dilated vessel has occurred.

The objective of an analysis of these data was to determine in percentage the efficiency of the correct recognition of artery stenosis and to determine their size with the use of the grammar introduced. Results obtained in this way have initially confirmed the great usefulness of syntactic methods in diagnosing ischaemic heart disease. On the image data tested, the efficiency of recognition amounted to 93%. It is worth emphasising that this value refers to automatic analysis and determining the size of the stenoses with the use of the procedure introduced, without a need to correct the external vessel contours manually. In this case, the value of the efficiency of recognition is determined by the percentage fraction of the accurately recognised and measured vessel stenoses compared to the number of all images analysed in the test. The recognition itself meant locating and defining the type of stenosis, e.g. concentric or eccentric. Comparative values of the size of artery stenoses have been obtained with the application of software used in the clinical practice, conducting morphometric artery analysis based on linear programming techniques and the minimum cost analysis (MCA) method of contour detection [18]. Images analysed in this way have undergone structural analysis aimed to compare the accuracy of the size of the stenosis detected by semantic actions defined in the grammar. In the case of compliance of the result obtained with the previously determined value, the analysis result was considered correct. On the other hand, if the type of stenosis (concentric or eccentric) was defined, the accuracy of identification was verified by a visual assessment due to the fact that alternative procedures, e.g. MCA do not offer a possibility to perform such an analysis automatically. The quoted value of correct identifications at the level of 93% stands for the percentage number of all accurately recognised cases, e.g. the types of stenoses and the correctly defined size of occlusion of the vessel lumen.

Fig. 3 shows examples of recognition of the looked-for lesions in the images of coronary arteries analysed in this paper. The recognised symptoms have been marked with a bold line.

The threshold of 7% of the misidentified size of stenoses in the test data set results from the non-optimal selection of the approximation accuracy threshold of the width diagram of a given vessel. In the research conducted, this size has been defined as 2 pixels for all cases, with image resolution of 300 dpi (this information is made clear by the analyser on width profiles shown on Fig. 3). Due to the fact, however, that the width profile approximation procedure can determine the value of the approximation threshold in a dynamic manner, therefore, in order to increase the recognition efficiency it is necessary to make its value dependent on the size of the analysed vessel lumen. In the case of smaller arteries and their ramifications, the approximation threshold should be respectively smaller, which will result in making it sensitive to small and subtle stenoses. In the case of bigger vessels, the threshold can be relatively bigger since as a result of approximation individual contour points do not lose important diagnostic information, which are determined by semantic actions. This solution shall be considered in further research aimed at enhancing the here-presented analysis technique of morphology lesions and intended to increase the efficiency and standardisation of the method based on analysis on a much larger set of data of medical images.

In the analysis conducted for each case of pathology, except for the location and recognition of degree of arteries stenoses, the syntactic description of recognised lesions in the form of the introduced structural symbols and derivative rules of grammar were obtained.

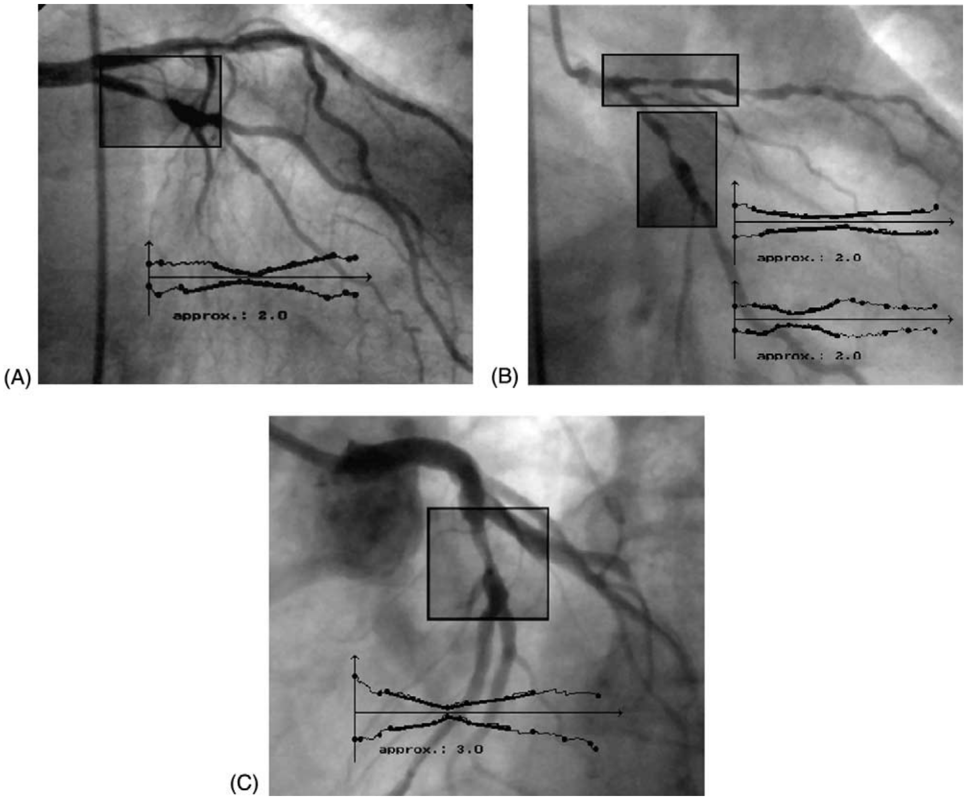

Fig. 3. (A–C) Results of recognition of disease symptoms with the use of syntactic methods of image recognition in the case of coronary arteries.

Those methods, apart from an ability to recognise pathology directly enable one also the conduct of a deeper semantic reasoning used, among others, to interpret the meaning of the recognised lesion from the point of view of diagnosis and further therapy. Such algorithms may not only support disease lesions, but they also constitute intelligent information systems imitating the method of image (pattern) interpretation and understanding as performed by a human being. In particularly, this information may also be helpful in categorisation of recognised cases of illness in archiving images obtained during diagnostic examination. Conducting of further evaluations of proposed algorithms on the wider sets of visual data will allow one to improve these procedures and their application in cardiological medical centres.

7. Conclusions

This paper presents results of computer analysis and diagnosis of coronary artery lumen stenosis with the application of syntactic methods of image recognition. Those stenoses can be the result of appearance of atheromatous lamina whose appearance in consequence can lead to the occurrence of heart ischaemic disease manifested in the form of stable or unstable angina or as myocardial infraction. The conducted research demonstrated that analysis of the correct morphology of coronary artery lumen is possible owing to the use of methods of structural analysis and image recognition, in particular of attributed grammars of the LR(1)-type. A deeper analysis and a number of research activities conducted in order to define a possibility to recognise lesions of coronary artery morphology have demonstrated a universality of the application of methods of mathematical linguistics in recognition and analysis of morphological lesions on medical images. Syntactic methods of image recognition, in particular context-free attributed grammars can be an additional tool to support early diagnosis of diseases of abdominal and chest cavities.

Those methods were so far used in the authors' earlier works to diagnose morphological lesions in main pancreatic ducts [15] and in upper sections of urinary tracts [17]. The results presented in this paper prove that the here-described methods can also have a wide application in the cardiology. Possibilities of wide application of this type of methods in analysis of medical images cause that they can also play an important role in picture archiving and communications systems (PACS), in particular as modules supporting the recognition and diagnosis of pathogenic lesions [19]. They can also be widely used in medical information systems as well as in syntactic multimedia indexation for archiving and search of concrete disease units in specialised medical databases.

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