Syntactic Analysis and Languages of Shape Feature Description in Computer-Aided Diagnosis and Recognition of Cancerous and Inflammatory Lesions of Organs in Selected X-Ray Images

Marek R. Ogiela and Ryszard Tadeusiewicz

We present new algorithms for the recognition of morphologic changes and shape feature analysis, which have been proposed to be used in a diagnosis of pathologic symptoms characteristic of cancerous and inflammatory lesions. These methods have been used so far for early detection and diagnosis of neoplastic changes in pancreas and chronic pancreatitis based on x-ray images acquired by endoscopic retrograde cholangiopancreatography (ERCP). Preliminary processing of x-ray images involves binarization, and, subsequently, pancreatic ducts shown in the pictures are subjected to the straightening transformation, which enables obtaining two-dimensional width graphs that show contours of objects with their morphologic changes. Recognition of such changes was performed using attributed context-free grammars. Correct description and diagnosis of some symptoms (eg, large cavitary projections) required two-dimensional analysis of width graphs. In such cases, languages of shape feature description with special multidirectional sinquad distribution were additionally applied.

Copyright © 1999 by W.B. Saunders Company

THE GOAL OF THIS REPORT is to present new algorithms used for the recognition of morphologic changes and shape feature description of the selected abdominal organs shown in x-ray images. These methods are aimed to facilitate diagnosis of cancerous or inflammatory lesions in these organs.

The aforementioned methods have been used so far for the diagnosis of pancreatic cancer and chronic pancreatitis, based on the analysis of x-ray images acquired by endoscopic retrograde cholangiopancreatography (ERCP) (Fig 1). The main symptoms characteristic of pancreatic cancer and chronic pancreatitis are local or global narrowings and dilatations of the main pancreatic duct, the appearance of cysts and cavitary projections in duct outer walls, and the development of abnormal

lateral branches of different orders (Fig 1A, B, and C). These symptoms can be recognized using attributed context-free grammars and languages of shape feature description, presented here, which enable quick detection of pathologic changes in the shape of the structures of interest.

PRELIMINARY PROCESSING OF X-RAY IMAGES ACQUIRED BY ERCP

Recognition of changes of interest using syntactic methods of image recognition is possible after subsection of the image to the sequence of operations constituting the preliminary image-processing stage. The aim of these operations is to obtain two-dimensional width graphs of the main pancreatic ducts, including their morphologic changes. The operations necessary for preliminary processing of x-ray images acquired by ERCP are presented in Fig 2.

Application of the methods of preliminary image processing, which were developed specifically for this purpose¹⁻⁵ and summarized in Fig 2, allow primary images to be obtained that represent contour graphs of real structures. An example of the result obtained by preliminary processing of x-ray images acquired by ERCP, using the aforementioned methods, is presented in Fig 3.

SYNTACTIC METHODS OF RECOGNITION OF MORPHOLOGIC PATHOLOGY CHANGES

We applied attributed context-free LR(1) grammar^{5,6} to detect morphologic changes indicative of certain pathologies in previously obtained graphs. Provided that primitives are correctly defined, such grammars enable the detection of all pathologic changes, significant from diagnostic point of view, ie, cysts, narrowings, dilatations, and branches. Application of attributes containing additional information, ie, height and width of the detected changes, makes it possible to diagnose doubtful and ambiguous cases.

We used an algorithm of linear approximation of these graphs using the fast polygonal approximation method⁷ to determine primary components describing the edges of pancreatic ducts in width

From the AGH Technical University, Institute of Automatics, Cracow, Poland.

Supported by the AGH Technical University under Grant No. 10.10.120.39.

Address reprint requests to Marek R. Ogiela, PhD, AGH Technical University, Institute of Automatics, 30 Mickiewicza St, Cracow PL-30-059, Poland.

*Copyright © 1999 by W.B. Saunders Company
0897-1889/99/1202-1007\$10.00/0*

Fig 1. ERCP pictures of pancreatic ducts with symptoms of chronic pancreatitis (A,B) and pancreatic cancer (C).

profiles, obtained previously. Subsequently, terminal symbols were attributed to individual segments, which approximated the graphs, depending on their angle of inclination. The scheme of this operation is presented in Fig 4. As a result, the strings of terminal symbols were obtained, which were input into shape-recognizing syntactic analyzers (parsers).

To make symptom recognition more effective and fuller, and simultaneously, to simplify the grammar, it was assumed⁵ that recognition of changes was conducted in both directions, ie, first, a duct was analyzed from its head to tail, and then from the tail to head.

Attributed Grammar Describing Morphologic Changes in Pancreatic Ducts

The following attributed grammar, using the terminal symbols presented in Fig 4, was applied to describe changes of interest:

$$G = (V_N, V_T, SP, STS),$$

where: V_N = nonterminal symbols set, V_T = terminal symbols set, SP = production set, and

STS = starting symbol. $V_N = \{\text{SYMPTOM, CYST, STENOSIS, DILATATION, BRANCH, DUCTUS_ACCESORIUS, HI, LO, P, S, G, I, N, NS, NG, NI, NN}\}$

$$V_T = \{p, s, ns, g, ng, i, ni, n, nn\}$$

STS = SYMPTOM

SP:

1. SYMPTOM $\rightarrow$ CYST	Symptom = Cyst
2. SYMPTOM $\rightarrow$ STENOSIS	Symptom = Stenosis
3. SYMPTOM $\rightarrow$ DILATATION	Symptom = Dilatation
4. SYMPTOM $\rightarrow$ BRANCH	Symptom = Branch
5. SYMPTOM $\rightarrow$ DUCTUS_ACCESORIUS	Symptom = Ductus_accessorius
6. CYST $\rightarrow$ HI P LO HI S LO HI NS LO	
7. STENOSIS $\rightarrow$ NS S NS G NS P S NS P I NG S NI NS I NI S	
8. DILATATION $\rightarrow$ S P NG S G NS S NS G NS	
9. BRANCH $\rightarrow$ I NI I NS S NG G NI G S NN S NS NN	
10. BRANCH $\rightarrow$ N G NG NI I P NI NN G P NN G S NI NN	
11. DUCTUS_ACCESORIUS $\rightarrow$ I NI S I P NS S NI NN NS NI	
12. HI $\rightarrow$ I G	
13. LO $\rightarrow$ NI NG	
14. N $\rightarrow$ n n N	$w_{sym} := w_{sym} + w_n; h_{sym} := h_{sym} + h_n$
15. NN $\rightarrow$ nn nn NN	$w_{sym} := w_{sym} + w_{nn}; h_{sym} := h_{sym} + h_{nn}$
16. I $\rightarrow$ i i I	$w_{sym} := w_{sym} + w_i; h_{sym} := h_{sym} + h_i$
17. NI $\rightarrow$ ni ni NI	$w_{sym} := w_{sym} + w_{ni}$
18. G $\rightarrow$ g g G	$w_{sym} := w_{sym} + w_g; h_{sym} := h_{sym} + h_g$
19. NG $\rightarrow$ ng ng NG	$w_{sym} := w_{sym} + w_{ng}$
20. S $\rightarrow$ s S	$w_{sym} := w_{sym} + w_s; h_{sym} := h_{sym} + h_s$
21. NS $\rightarrow$ ns ns NS	$w_{sym} := w_{sym} + w_{ns}$
22. P $\rightarrow$ p	$w_{sym} := w_{sym} + w_p; h_{sym} := h_{sym} + h_p$

Fig 2. Stages of preliminary processing of x-ray images acquired by ERCP.

In this grammar, the first group of productions defines pathologic symptoms to be recognized, and the semantic actions, connected with them, determine the type of the discovered lesion. A substitution like Symptom = Cyst, Stenosis, Dilatation, Branch, Ductus_Accesorius stands for what kind of affection (a pathologic syndrome), from the diagnostic viewpoint, has been detected. Variables h_e and w_e (for $e = p, s, ns, g, ng, i, ni, n, nn$) mean the

Fig 3. Graph representing contours of pancreatic duct shown in ERCP picture presented in Fig 1A. Note morphologic changes characteristic of chronic pancreatitis.

height (namely, the difference in the levels at the segment's origin and end) of the e -th terminal and its width (ie, the length of its projection upon axis OX). Subsequent productions describe various kinds of cysts, narrowings, different shapes of branches and dilations, and the accessory pancreatic duct. The last group of productions describes ascending and descending parts of structures under examination with different angles of inclination. The aim of the semantic actions of these productions is to determine the height and width of the recognized change.

Languages of Shape Feature Description and Diagnosis of Ambiguous Cases

Due to the fact that precise definition of all potential shapes of the changed structures is not possible, the structures of interest were also analyzed using languages of shape feature description,⁸ which enables one to base recognition process on the analysis of features and to define the nature of these shapes (excavations or projections). These languages allow changes to be detected without the necessity to define precisely their morphology, but only based on transitions between sinquads, ie, distinguished directions in space,

Fig 4. Scheme of encoding of width graphs as terminal symbols of the grammar that describes them.

Fig 5. Scheme showing distribution of sinquads for analysis of morphologic changes.

where width graph-approximating segments are situated. Intervals, defining directions of the main sinquads, are presented in Fig 5. Analysis using languages of shape feature description is more general and enables one to identify projections of all kinds, branches, and narrowings, even in situations when such changes were not recognized by context-free grammar, described earlier.

Results of Recognition Based on Syntactic Analysis

In the present studies, syntactic methods of image recognition delivered practically whole information on morphologic changes in the outer walls of the structures of interest. The parser, constructed for the developed grammar, yielded good results regarding recognition of the changes concerned. Furthermore, sequential multiple entry transducer was implemented in the procedure of shape feature analysis, which aided the process of recognition of pathologic symptoms.

The work is based on 100 x-ray images of pancreas with neoplastic changes and symptoms of chronic pancreatitis, as well as normal pancreatic

Fig 6. Results of recognition of pathologic changes in the pancreatic duct with chronic pancreatitis, using syntactic methods. Circles designate ends of segments, approximating the pancreatic duct. Accuracy of approximation is $\epsilon = 2$.

ducts. Figure 6 shows an example of the recognition of changes of interest in the ERCP picture, analyzed in this report. The symptoms recognized using the procedure presented here are marked with a bold line.

CONCLUSIONS

The present study confirmed the usefulness of syntactic methods, and especially context-free LR(1) grammars and languages of shape feature description in the analysis and diagnosis of medical images. Efficacy of the methods, described in this work, in computer-aided diagnosis of cancerous and inflammatory lesions based on ERCP pictures can be preliminarily estimated at 85%; however, it should be mentioned that these methods are constantly being improved and tested on larger and larger data sets. Furthermore, studies are in progress on the application of these methods in the diagnosis of pathologic changes in other structures, eg, analysis of coronary vessels, and in ophthalmoscopy, which confirms versatility of the proposed algorithms and their applicability to the analysis of morphologic shapes of other anatomic structures as well, with special consideration given to diagnostics of abdominal and chest organs, based, for example, on computed tomography images.

REFERENCES

1. Ogiela M: The skeletonization of the binary ERCP images. *Electrical Engineering*, AGH Technical University Press, 15:33-53, 1996
2. Ogiela M: Computer analysis of ERCP images with an attempt at diagnostics. *Pol J Med Phys Engineer* 2:27-47, 1996
3. Ogiela M, Tadeusiewicz R: Recognition of some types x-ray images for medical diagnosis. *Biocybernet Biomed Engineer* 17:69-91, 1997
4. Ogiela M: Methods of the straightening transformation and analysis of outer contours of objects in medical image recognition. *Computer Science*, AGH Technical University Press, 1:101-110, 1998
5. Ogiela M: Languages of shape feature description and syntactic methods for recognition of morphological changes of organs in analysis of selected x-ray images. *Proceedings of SPIE's International Symposium Medical Imaging 1998*, San Diego, CA. SPIE 3338:1295-1305, 1998
6. Waite WM, Goos G: *Compiler Construction*. New York, NY, Springer-Verlag, 1984
7. Sklansky J, Gonzales V: Fast polygonal approximation of digitized curves. *Patt Recogn* 12:327-331, 1980
8. Tadeusiewicz R, Flasiński M: *Pattern Recognition*. Warsaw, Poland, Polish Scientific, 1991