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Recognition of Objects in Images of Paper Based Line Drawings

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Abstract

This paper presents an algorithm for recognition of objects in skeletonized line drawings. The proposed algorithm employs the grammar to define the set of structural descriptions of objects and detects the elements of these objects during the process of their recognition under the control of the grammar. For recognition new objects grammars of these objects must be only specified without rewriting of the recognition program. Experimental results dealing with recognition of schematic diagrams, maps and numeric inscriptions confirm high processing speed, efficiency and flexibility of the algorithm.

1. Introduction

The skeletonization procedure is widely used for preprocessing of line drawings. There are many algorithms [1-8] which define skeletons of binary pictures in a number of ways in the continuous as well in the discrete plane. We use modified version of the algorithm [8] for skeletonization of binary pictures. This algorithm implements original definition of objects skeleton, has higher processing speed than conventional skeletonization algorithms and produces skeleton, representing unlike [2-5], not isolated points but thin lines.

Input data for recognition algorithms [9,10] represent not the picture but its description in the form of the chain or the graph of connected primitives or terminal elements. The fact that these algorithms use only one version of representation the picture as consisting of some parts leads to dependence recognition results of the quality of this representation. Principal features of proposed recognition algorithm are as follows. First, the original grammar is used for defining the set of permissible descriptions of detected object (syntactic approach) and, secondly, in general different versions of picture decomposition are tested and detection of terminal elements is carried out not before but during the object recognition under the control of the grammar.

2. Recognition of objects in skeletonized picture

Syntactic approach is used for recognition of skeletonized pictures. This approach is the most preferable for recognition of non-standard or handdrawn objects. Some geometric features and way of drawing can be changed from one sample to another of these objects. At the same time skeletonization procedure leads usually to some distortions of processed picture and therefore to changeable skeleton representation of standard objects also.

Under syntactic approach some grammars for defining the set of structure descriptions of the detected objects are usually used. The proposed grammar and the recognition algorithm using this grammar are described below.

2.1. Description of grammar

The skeleton graph consists of arcs corresponding to line skeleton segments and nodes corresponding to ends of these lines. Picture analysis results in extraction all subgraphs of skeleton graph which can be defined by the following grammar

$$G=\{ V_T, V_N, P, S \},$$

where $\mathbf{V_T}$ and $\mathbf{V_N}$ are sets of terminal and nonterminal symbols, **P** is the set of production rules and **S** is the starting symbol.

The set $\mathbf{V_T}$ of terminal symbols consists of horizontal, vertical and inclined line segments, concave and convex curved segments, initial and empty terminal symbols also. Each terminal symbol can be assigned to some part of the skeleton graph which has two (tail and head) end points and is called the terminal element. These end points are identical for initial terminal element and for the closed curved segment also. The initial terminal element is one of skeleton nodes in the picture. The empty terminal element is the "white" line segment defining interconnection of not connected parts of the picture. Any other terminal element **b** consists of one or some skeleton line segments and can be defined by direction from tail to head point, length, number and directions of lines starting from graph node corresponding to head point of **b** and some other features.

The set $\mathbf{V_N}$ of nonterminal or structural symbols is the set of marks corresponding to end points of terminal

elements in the skeleton graph. Production rules from the set **P** have the form

$$A \rightarrow aB \text{ or } A \rightarrow b,$$

where **A** is the nonterminal symbol, **B** is one or some nonterminal symbols and $a,b \in V_T$.

While processing the picture some subsets of nonterminal symbols can be assigned to nodes of the skeleton graph. Each of production rules results in replacing nonterminal symbol **A** in the graph node by terminal element **b** (with tail point in this node) and 0, 1 or some nonterminal symbols in the head point **p** of **b**. Let $S_1(p)$ and $S_2(p)$ be sets of nonterminal symbols corresponding to point **p** before and after substitution of **aB** for **A**. The following rule for $S_2(p)$ is valid. The $S_2(p)$ includes nonterminal symbols from $S_1(p)$ and **B** except those which are common for these subsets:

$$S_2(p)=S_1(p) \cup B \setminus S_1(p) \cap B.$$

Generation features of the grammar can be also described employing the following notions of joint and primary fragment. The joint is the pair $J=\{$**end point,** $s \in S_N\}$. The primary fragment **f(b,A,B)** is determined if subsets $A,B \in V_N$ are defined as corresponding to end points of terminal element **b**. Two primary fragments can be joined along their common joint only. This operation is like to using one of production rules and results in producing not primary fragment containing no joint **J**. Generation of the picture by the grammar is the process of joining fragments that is considered to be over if the certain fragment containing no joints is produced.

2.2. Grammar example

Let us consider the grammar ***G*** generating rectangles with the number of horizontal line end points at vertical sides of these rectangles (Fig. 1).

The grammar **G** is the following set

$$G=\{ V_T, V_N, P, S \},$$

where

$V_T = \{ p_0, h_1, h_2, h_3, h_4, v_1, v_2 \}$,

$V_N = \{S, A, B, C, D, E, F, G\}$;

$P = \{ S \rightarrow p_0\, AG,\ A \rightarrow h_1\, B,\ A \rightarrow h_2\, C,\ B \rightarrow h_1\, B,$
$B \rightarrow h_2\, C,\ C \rightarrow v_1\, D,\ D \rightarrow h_3\, E,\ D \rightarrow h_4\, F,$
$E \rightarrow h_3\, E,\ E \rightarrow h_4\, F,\ F \rightarrow v_2\, G \}$

Nonterminal symbols of the grammar are the marks **A-G** placed in Fig. 1 near head points of terminal elements. Initial terminal element p_0 is the skeleton point with some features. All other terminal elements are either horizontal or vertical line segments. They are defined not only by direction from tail to head point but by some features of their head points also. For example, terminal element h_1 is the vertical line segment with the following features: 1) tail point is lower than head point, 2) three line segments start from head point and 3) one of them is the horizontal line segment with right to left direction.

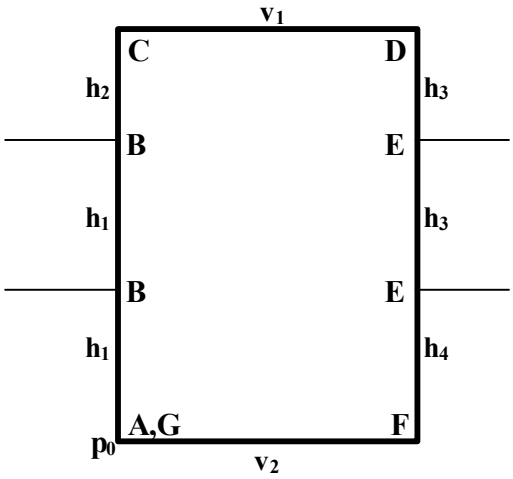

Figure 1: Structural description of the rectangle

2.3. Recognition algorithm

Initial step of the recognition procedure consists in detecting skeleton points satisfying to features of the initial terminal element. The primary fragment, containing this element has one or some joints and represents at this step the intermediate fragment **F** of the object detected. Let **J** be joint of the fragment **F**. The chain **C(J)** of joined primary fragments will be considered as permissible for **J** if tail point of this chain has joint **J** and head point has either no or only joints coinciding with ones of the generated fragment **F**. Subsequent steps of the algorithm consist in modifying the fragment **F** by tracing in the picture permissible chains of primary fragments and joining these chains with the fragment **F**. Object recognition procedure results either in 1) object detection if the fragment **F** containing no joints is produced or 2) cessation of object recognition if no permissible chain for the joint of the fragment **F** can be detected.

Some features of the algorithm for detection permissible chains of primary fragments will be considered below. Let **n** be the number of primary fragments in traced part of the chain **C(J)**; J_n be the joint at head point of this traced part and $F(J_n)$ be the list of primary fragments $f_{i,n}$ that can be joined to J_n. One of three following results can be on the next step of the algorithm:

1) The primary fragment $f_{i,n} \in F(J_n)$ is detected in the picture with head point that has either no or only joints coinciding with ones of the generated fragment **F**. It means that generation of the chain **C(J)** is over.

2) The fragment $f_{i,n}$ is detected with head point that has joint J_{n+1} not coinciding with any other joint of the

fragment **F**. In this case the index number $\mathbf{k_n=i}$ of the fragment $\mathbf{f_{i,n}}$ in the list $\mathbf{F(J_n)}$ is stored and search of the fragment $\mathbf{f_{i,n+1} \in F(J_{n+1})}$ is fulfilled.

3) Not a primary fragment $\mathbf{f_{i,n}}$ can be detected in the picture. In this case return to the previous joint $\mathbf{J_{n-1}}$ is fulfilled for search in the picture the primary fragment $\mathbf{f_{i,n-1} \in F(J_{n-1})}$ with the index number $\mathbf{i > k_{n-1}}$. If such fragment is detected index number $\mathbf{k_{n-1}=i}$ of this fragment is stored and next step of the algorithm is started. Otherwise return to $\mathbf{J_{n-2}}$ joint is fulfilled and so on. At last, if for the first joint **J** no other primary fragment can be detected object recognition is stopped and search of the next initial terminal element is started.

There are two most widely used types of recognition algorithms using syntactic approach. Algorithms of the first type [9,10] consist of two following steps. At the first step analyzed picture is represented as the chain or the graph of connected terminal elements. At the second step syntactic analysis of such chain or graph is carried out. Efficiency of these algorithms depends to a great extent on the quality of picture segmentation. The algorithms of the second type [11-14] overcome this deficiency by detecting at the first step all terminal elements in the picture that leads to much more memory and time expenses and to more complicated analysis procedures of such data also.

The proposed algorithm is based on the concept of tracing and takes up an intermediate position between these two types of algorithms. Detection of terminal elements is fulfilled in the process of recognition under grammar control that usually leads to lesser number of computations at rather high reliability of object recognition. The other essential peculiarity of the algorithm is that some features of terminal elements and employment of special tracing procedures makes it possible to detect objects crossed by lines or touched to other objects.

3. Experiments

Objects goal of recognition is detecting of objects consisting of lines and having structural features in line drawings and getting the structural description of these objects also. Circuit symbols in schematic diagrams, symbols marking point objects in the map, numerals and letters are some examples of such objects. The software for recognition objects in skeletonized line drawings is developed. For introducing a new object only the grammar of this object must be specified without rewriting the software. The grammar can also describe predefined cases of objects touching, for example touching circuit symbols to connecting lines or numerals to graphics (Fig. 2). Just now for slant (more than 22^0) and non-slant numerals or letters different grammars must be used.

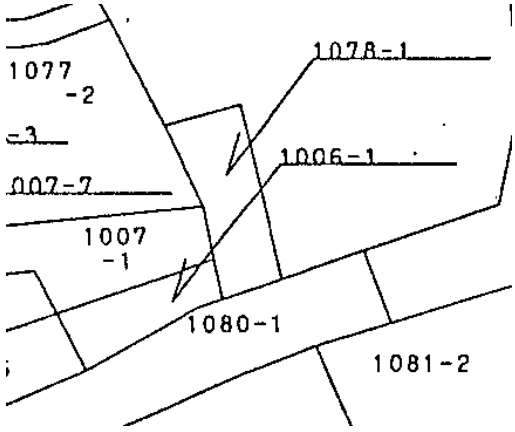

Figure 2: Touched numerals to graphic in cadastral map

More than thirty hand-sketched schematic diagrams, a variety of circuit and maps symbols and more than 700 hand drawn digitals have been used for testing the developed algorithm. Used schematic diagrams comprise 22 varied types of circuit symbols and 70 grammars were used for recognition of these diagrams. The recognition process of the diagram consists in sequential search in the picture of the objects given by these grammars. The recognition rate of extracted essential components is 95% on an average. The developed software makes available for operator a convenient way for checking recognition results and for hand input of unidentified essential components via an interactive graphic editor.

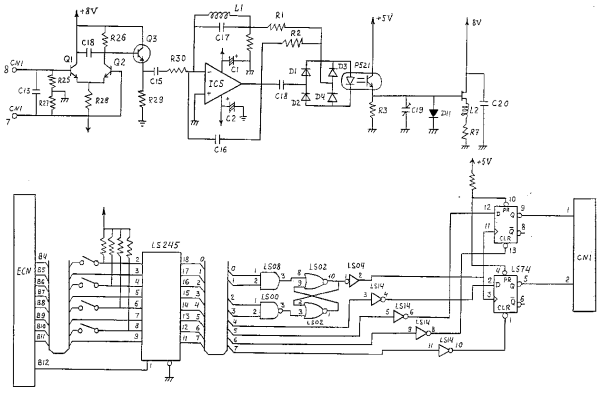

Figure 3: Schematic diagram

An example of hand sketched schematic diagram is shown in Fig. 3. Size of the picture is 270x170 mm. After scanning this picture with the resolution 200 dpi the volume of noncompressed TIFF file is 574 kbyte. The time for skeletonization of this picture (IBM PC 386 DX 33) takes 25 sec. The volume of skeleton representation after piecewise linear approximation with the threshold value

equal to 4 pixels is 13.2 kbyte. The number of used grammars for recognition this diagram is 58. The total time for recognition the diagram takes 5 sec., including preprossessing operations. Only two essential components are unidentified owing to noise and to drawbacks of skeleton representation. In Fig.3 the recognized circuit symbols presented by their skeletons are shown. Areas of two unidentified circuit symbols are shown by dashed rectangles.

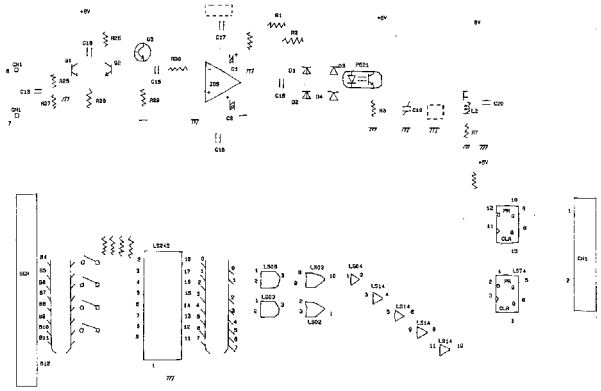

Figure 3: Recognized circuit symbols

Main results of handdrawn numerals recognition are as follows. Total number of pictures is 700; the recognition rate is more than 95% (0.5% of mistakes and 4.5% of unidentified components); recognition time is 0.1 sec. for one figure on an average (preprocessing takes 0.098 sec. and analysis of figure skeleton takes 0.002 sec.). The way of numerals drawing has no essential constraints. The example of used picture is presented in Fig. 4.

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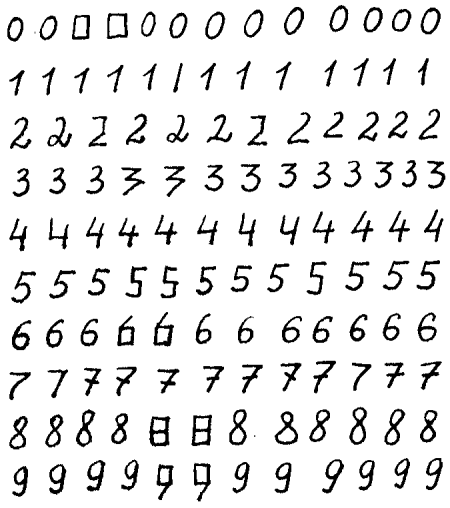

Figure 4: Handdrawn numerals