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DRAWING RECOGNITION: SYSTEMS AND TECHNOLOGIES

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Abstract. In this paper, the problem of mechanical drawing image interpretation is analysed. Main requirements to mechanical drawing interpretation are defined. The main stages of the MD image interpretation technology are given. The MD image models compatibablw to CAD systems are described. Overview of line-drawing vectorization systems is given. Practical experience of MD image recognition is shown.

Key words: line-drawings. image vectorization. graphical primitives. CAD models.

1.Introduction

Multimedia tools for planning and learning of work on complex engineering products and projects are now being developed. They have improved communication to work people but are still not automatically or reliably derived from raw engineering data. In spite of already quite long period of using computers for design. manufacture and maintenance processes. there are still many drawings that should be transferred into electronic format. Manual input of drawings into CAD systems is a slow and expensive process. During last decade automatic input devices called scanners started to be used for this task. Their usage allows to quickly transform drawings in a digital raster form but requires a highly developed software to convert scanned images in a required vector form.

The desirable output of this transformation for engineering drawings would be a 3D model of an object drawn at the ED projections. There exist quite many papers discussing such a transformation although there are not know automatic solutions of this task. As an intermediate step could be an automatic transformation of EDs into 2D models suitable for such CAD systems like AutoCAD.

There known many systems that perform automatic image vectorization and allow one to represent the image in terms of simple graphic primitives [1,2]. Recently there were developed research systems that allowed to recognise more complex primitives. Examples of such systems are French systems REDRAW and CELLESTIN [3.9]. Japanese system [6]. American systems [4,8], Israilian system [11] and Belarussian systems [5,10]. Most of the developed systems can recognise separate primitives but the whole process of recognition of a full set of engineering drawing primitives is still far from its solution.

Another very important task in this process is recognition of 2D objects and building a 3D object model from orthogonal ED projections [2]. Most of the professional CAD systems can build 3D representations from 2D projections, nut only as 'wire-frame' images and/or extensions. There are no commercial systems which can decompose a set of 2D projections and re-integrate them into an integrated set of 3D solid primitives and a fully Boolean-integrated solid model.

In this paper. the problem of MD image interpretation is analysed. Main requirements to mechanical drawing interpretation are defined. The main stages of the MD image interpretation technology are given. The MD image models compatible to CAD systems are described. Overview of line-drawing vectorization systems is given. Practical experience of MD image recognition is shown.

2. Requirements of Line-Drawing Interpretation Technology

It is clear that an ideal solution to a line-drawing image interpretation problem could be by full automation of all of the manual input tasks and presentation of dcision-support information to solve all of the corresponding applied tasks. However, the current level of the image recognition capability does not allow execution of this task totally automatically, i.e. without human intervention. The numerous research papers show that it is practically impossible to recognize line-drawings fully automatically because they were prepared to be read by a human and contain many object types with different fonts, orientation, size, etc. Therefore, we can summarize that the main aim of a graphic input system design is to minimize this intervention [7].

The impossibility of solving this task automatically indicates a combined technology which includes, together with automatic image vectorization and automatic object recognition, interactive object interpretation techniques. Such a combination could allow a customer-aceptable balance to be reached between quality, time and automation level of the line-drawing digitizing process. Based on the above, we introduce the following main requirements to the line-drawing interpretation technology:

1.The output of a line-drawing interpretation system should be represented in terms suitable for CAD or GIS systems. This means that the identified objects, MD entities should be capable of use in CAD or GIS systems directly without further manual work.. It is desirable to obtain an output image description at a much higher level (blocks, high-level primitives, 2D and 3D objects).

2.Since no automatic solution to a line-drawing interpretation task exists now, the interpretation technology should be based on two parts:

- automatic image vectorization and
- automatic-interactive object recognition.

The operator's workload in the interactive part should be minimized.

3.Automatic image vectorization should achieve a satisfactory duration and vectorization quality. If quality of the vectorized image is unsatisfactory (there are distortions, object defects) it leads to a high workload in interactive image editing, and all the advantages of automatic processing could be lost.

4.Output of the image vectorization should be a data structure that is suitable for automatic-interactive object interpretation. It should include all possible useful information that is extracted from a raster image. Information lost at this step could lead to incorrect object recognition and give many errors in the output.

5.Automatic object recognition techniques should be used wherever they give a satisfactory result. In particular, they are very important for recognition of elongated, area objects where manual input requires much time and effort.

6.For objects to be recognized, a compromise should be found between automatic and interactive techniques to provide the required processing time and line-drawing accuracy. It should be decided in advance which types objects will be recognized automatically and which will be recognized interactively.

7.The automatic recognition output should enable simple correction of recognition errors. The interactive techniques should allow, on the one hand, simple correction of recognition errors and, on the other hand, they should be powerful enough to label unrecognized objects. They should also be intelligent enough to input not only object points or segments but to input and recognize objects or their substantial parts. The interactive interpretation software should be organized in such a way as to be user-friendly.

8.The processing time of this entire automated technology should be better than half of the time for manual digitizing.

9.It should be possibe to interrupt the process at any processing stage and return to the previous stage. If the processed stage, especially the automatic one, has resulted in errors and distortions, it should be easy enough to return the process to the previous stage.

10.The digitized line-drawing should include maximum the possible object information and, at the same time, should be stored in minimum possible data volume. This mainly concerns map processing. It is almost always better to have more objects and characteristics in the output data base so that they can be available for further digital map work.

11.The required accuracy of object representation (geometric coordinates) should be provided. This requirement is very important for map digitizing, because errors in the map object coordinates could introduce further errors in later digital map processing.

12.The developed technology should be run on industry-standard computers (like IBM PC 486, Pentium, etc.). It is necessary to have such systems running on normal computers to enable many small companies to use them widely.

3. Methodology of MD Interpretation

We consider the main stages in the process of interpretation and transformation of graphic information from one level of representation to another one, with a higher level of line-drawing abstraction. The final aim is to generalize the data obtained from a scanner to a level necessary for line-drawing representation in CAD systems.

From the general task of automated conversion of line-drawings to CAD or GIS representation one can extract five main and more important tasks (or successive stages):

•1 scanning of the line-drawing to obtain a raster (binary or gray-scale) image;

•2 vectorization of the raster image to obtain a vector image model in terms of simple graphic primitives (segments);

•3 recognition of the vector image model to obtain image representation in terms of universal MD entities;

•4 understanding of the resulting image representation to get specific 2D objects contained in CAD library with their parameters and relations;

•5 complete reconstruction of 3D engineering objects with all "semantic" attributes.

Schematically it could be written as follows (Fig.1):

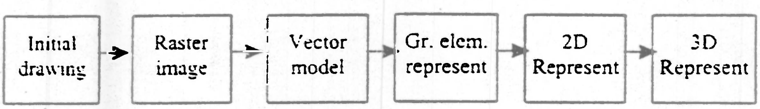

Fig.1.Scheme of line-drawing interpretation.

In principle, the solution to each task can be used separately, without further processing. For example, the scanned image could be compressed and used for storage or transmission. The vectorized image could be used in CAD systems but it will require a lengthy interactive job to create further the required ED digital models. To be a practically useful system, it should supply the main high-level entities defined, for example, by Initial Graphics Exchange Specification (IGES). Therefore, the solution of the third task must satisfy industrial requirements.

The generic solution to the fourth task is very complex, although its particular solution need not be very difficult. An incorrect solution of this task can significantly increase the volume of interactive image editing.

Moreover, the fourth task is very closely connected with the fifth task, because many modern CAD systems operate with complex 3D objects which can be recognized only after analysis of all orthogonal projections and even isometric pictures. But the fifth task is more a task of geometrical modeling. So, we consider that at present, the more important issue in image interpretation is the task of correct recognition of CAD entities.

4.MD forms compatible to CAD

From a raster form, the image should be transformed into the form that could be used as an output of a line-drawing interpretation system. At each next level of image representation a higher level of abstraction is achieved. We can extract the following line-drawing image representations compatible to CAD:

- in terms of graphic primitives for CAD systems;
- in terms of MD entities for CAD systems;
- in terms of 2D objects;
- in terms of 3D objects.

Movement from one level to another provides an increasingly higher level of element abstraction suitable for CAD. Consider these levels in more detail.

1. Image representation in terms of graphic primitives or graphic primitives form (P-form).

The graphic primitives could be divided into simple and complex ones. The simple primitives correspond to connected components having the same parameters (lines, arcs, characters). As graphic primitives we consider straight lines and circular arcs (conics and splines can also be added), characters and special symbols. A simple graphic primitive consists of one or more segments.

The complex primitives consist of simple ones divided by gaps or having different parameters (text strokes, broken lines, lines with different thickness, etc.). Some simple primitives are united to form one complex primitive on the basis of the same geometric (they have equal coefficients of equation), or logical (words which consist of characters, solid areas, etc.) characteristics. Examples of some graphic primitives are shown in Fig.2.

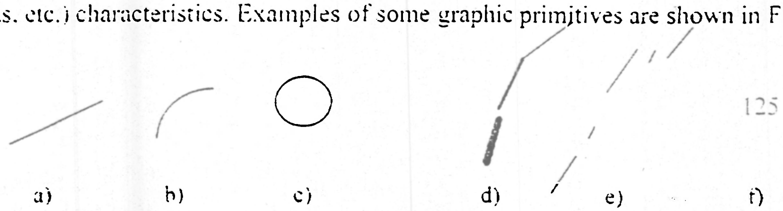

Fig.2. Examples of graphic primitives: simple primitives: (a) straight line, (b) arc, (c) circle; complex primitives: (d) stroke of symbols, (e) line with different thickness, (f) dashed line.

This form could be used for further applied tasks although it is quite a low level of abstraction. It is also a suitable material for image archives. In this case, the volume of data is decreased and the contents of data become more natural for CAD systems in comparison with simple vector image representation.

2. MD entities form (E-form) represents the contents of the MD image in terms of generic MD entities, which are independent on the MD domain and reflect a semantic part of MD. They are :

- contour lines, symmetry axes (represented by dash-dotted lines),

- hidden contour lines (represented by dashed lines),
- matter areas (represented by crosshatchings),
- dimensions (thin lines with arrows, witness lines and so on),
- annotation text, etc.

The MD entities could also be separated into simple and complex ones. Simple entities are combinations of the graphic primitives (or their pieces) and are used to represent simple MD entities like a symmetry axis, a crosshatching line, the border of matter area, etc. In some cases, the simple entities can coincide with primitives but in a general case they are more complex notions (for example, a symmetry axis can be represented by a polyline consisting of a few dot-dashed straight lines and circular arcs; the border of hatched area can consist of thick, thin and dot-dashed lines, etc.).

The complex entities are used for description of more complex MD structures - scenes - and can be presented as combinations of graphic primitives and a set of other simple and/or complex entities. Examples of complex entities are a crosshatching area (a set of hatching lines, bounded by one or more borders); a symmetry center; a circle or a circular arc with denoted (by crossed symmetry axes) center; a set of concentric circles having the same center; dimensions of different types, etc. Examples of some MD entities are shown in Fig.3.

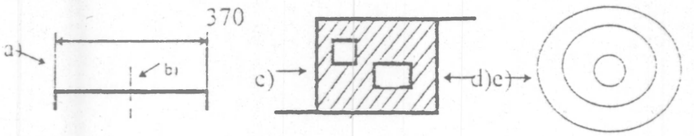

Fig.3.Examples of MD entities: simple entities: (b) symmetry axis, (d) border of crosshatching area; complex entities: (a) dimension, (c) crosshatching area, (e) a set of concentric circles.

The MD entities can be used as a base for MD understanding, i.e. for extraction of 2D objects according to a concrete applied field with corresponding CAD library (for example, gearbox, shafts, screws, etc.) and/or for the problem of 3D image model reconstruction.

As concerning the formats of data representation the more popular formats to represent the recognized graphic primitives and MD entities are Initial Graphics Exchange Specification (IGES) format or DXF, DXB file format of AutoCAD system.

5.Commercial Systems For Line-Drawing Vectorization

In the mid-to late 1980s, document image analysis began to grow rapidly as results achieved in hardware development allowed the processing of images in a reasonable cost and time. At present, there are many systems, including commercial ones, that perform a conversion of scanned raster images into a vector form.

The magazine 'Advanced Imaging' publishes every year a buyer's guide where the large list of systems working in image analysis area is given [13]. The list is classified into various topics and the special sub-topic devoted to vectorization of cartographic images is extracted. The sub-topic list includes the following companies:

Able Software Company, AccuSoft Corp., Alpharel, Arbor Image Corp., Audre, colourSoft Inc., CPI, Digist Software, ERDAS Inc., Grumman InfoConversion, GTX Corporation, Horizons Technology, InfoGraphix Technologies, Intergraph Corp., MicroImages Inc., MST, Pacific Gold Coast, Rorke Data Inc., Softdesk Imaging Group, Sovereign C.S. Ltd., Vidar Systems Corp.

Practically all the existing systems are restricted to image vectorization and doing very little recognition. They usually get output in terms of very simple primitives like Lines, Polylines, Arcs, Circles, Dots, Squares, Rectangles, and some others. Outputs in AutoCAD DXF, DXB, IGES, HPGL formats are the most popular ones. The scanned information is usually is usually black and white (binary) image represented in such formats as PCX, TIFF, SGI, PROCAD and uncompressed bitstream. Practically every system includes a set of interactive facilities to edit, rectify, and beautify images.

The vectorization systems sold in the Russian market are shown below, taken from the paper [12]. As one can see from Table 1 there are many systems in this market. It could be explained by two main reasons. The main development period for GIS technologies in USA and Western Europe was in the time when scanning technology was very expensive and used quite rarely. That is why the main input of cartographic data was made by digitizers. On the other hand, Western countries more often use the technology of map digitizing and updating on the basis of remote sensing images obtained from aero- or satellites. In Russia, the main interest in GIS technologies was during recent years when the scanning technologies and scanners became inexpensive and were more often used. Systems for image processing and vectorization were developed early and their transference into PC computers was made very quickly. Together with the fast growth of GIS systems, scanning technologies became very popular and have now become practically the main form of map input.

Table1.Classification of image vectorization systems existed on Russian market.

System name	Environ-ment	Input file format	Output format of vector data	Output format of attri- butes	Work with seman tic data	Vectori - zation mode	Work with color
Easy Trace 2.1	DOS	PCX, RLC	DXF,GEN, DAT	DBF	Yes	S A, M	Yes
MapEDIT 2.1	DOS	PCX	DXF, MIF	DBF, MID	Yes	S/A, M	Yes
TRACK 3.3	DOS	TIFF,PCX	GEN, DXF, MIF, PD, PLANAR, PLOS, FORA	DBF, ASCII	Yes	A, S/A, M	No
POCBIT	DOS, Windows	TIFF,PCX	DXF, DXB, ASCII - CREDO)	ASCII	Yes	A, S A	No
AutoVEC 1.7	DOS	PCX	DWG, DXF, EPS, IGES	DBF	Yes	A, S A, M	Yes
DigiMAP	Windows	BMP	DXF	DB	Yes	A, S A, M	Yes
Colour-Fast 2.0	Windows Windows NT	PCX,BMP	DXF, MIF	DXF, MIF	No	A	Yes
Video-digitizer for AutoCAD	DOS	PCX, TIFF	DXF, DXB	No data	Yes	S/A, M	No
CAVRIN	DOS	BMP	DXF	DBF	Yes	S/A, M	No data
GEOR	DOS	PCX	DXF	DBF	Yes	S/A, M	Yes
INTELVEC	DOS	PCX, TIFF	DXF, FIM, HPGL	Internal format, FIM	Yes	A, S/A, M	Yes
Vectometr	DOS	DGN,TIFF, PCX	DXF	No	No	A, S/A, M	No
Vectory 4.1	Windows Windows NT	RLC, PCX, BMP, TIFF G3/G4, CALS 1, NIFF, C4	DXF, DXB, PIC, ASC, DWG, AutoCAD ADS VC4 input	MIF-MID, DLG (in the next one update)	No	A, M	No
Spotlight 2.0	Windows Windows NT	RLC, RCX, BMP, TIFF G3/G4, CALS 1, NIFF, C4	DXF, DXB, PIC, ASC, DWG, AutoCAD ADS VC4 input	MIF-MID, DLG (in the next one update)	No	S A, M	No

CKM-Vectorizer 2.0	DOS. Windows	PCX. TIFF	DXF. MOS. F1. F1M. FT. F2OS. SLF. FTM	DBF. F1. F1M. FT. F2OS. SLF. FTM	Yes	A. S/A. M	Yes
AUTOVECT	Windows	LRD. PCX. TIFF	DXF	DBF	Yes	S/A. M	No data
AUDRE0/300	windows NT. UNIX HP-UX. SUN OS. Solaris	TIFF gr.3. gr.4. CALS. CALS 2. VIDAR	Post Script. IGES. DXF. CGM. HPGL. GEN	No	No	A. S.A	No
IVEC IGEO-VEC	DOS. Windows Windows NT. UNIX-CLIX	RGB. TIFF. PCX. BMP. CIF. COI. CIT. RLE. RLC. ..	DGN. DXF. DWG. ASCII	DMP. ASCII. DBF	Yes	A (IVEC).S-A (IGEOVEC). M	Yes
ArcScan (in Arc Info)	UNIX	TIFF. RLC. SUNRASTER....	Arc Info. expert formats Arc/Info	Arc.Info. export formats Arc/Info	Yes	A. S.A. M	No (Arc/Info)
GIS "INFOSO"	DOS	PCX. TIFF. GIF et al.	DXF		Yes	S-A. M	Yes

6. Practical Results

The system for interpretation of engineering drawings has been developed on IBM PC computer in C language. The input binary images are obtained from engineering drawings with size A4-A1. usually scanned with a resolution of 20 pixels per 1 mm and 400-600 DPI. The raster data for the processing are represented in PCX. TIFF or MSP format. Output data are represented in the IGES or AutoCAD DXB. DXF files. The vectorization process has been developed early [5]. modified for MD image vectorization and it was successfully tested on many MD images. For example. A4 MD images of average saturation scanned with 400 DPI are vectorized during 1-2 min on IBM PC Pentium. Vectorization of A2 format MD image is performed about 7-12 min.

At present. we continue to develop a software realizing the recognition process based on the introduced principles which allows to obtain the image representation in terms of universal CAD entities.

The recognition software includes programs for recognition of straight lines. circular arcs and circles. hatched areas (hatching lines and areas boundaries). symmetry and broken lines. some types of dimensions (linear. diametral. radial. angular). closed areas bounded by contour lines. The extracted MD elements are aligned and transformed to DXF AutoCAD format. The performed experiments show enough good quality and noise stability of recognition. Recognition time for not very complex images of A4 format (about 1000 initial segments) is equal to 2-4 min and for enough saturating images (about 3000 segments) is equal to 10 min on IBM PC Pentium. Example of MD complex image vectorization, primitive recognition and smoothing is shown in Fig.4.

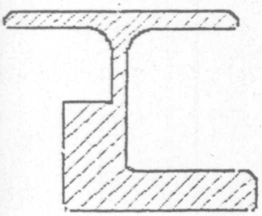

Fig.4a. Detected crosshatching area of the drawing.

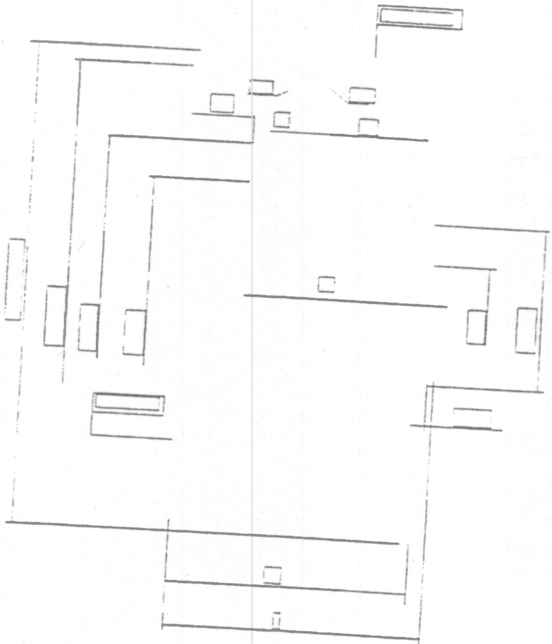

Fig.4b. Detected dimensions of the drawing.

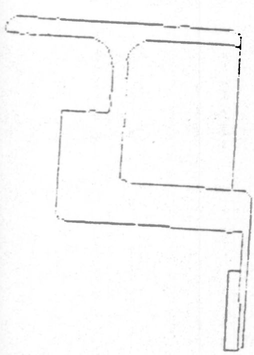

Fig.4c. Detected contour blocks.

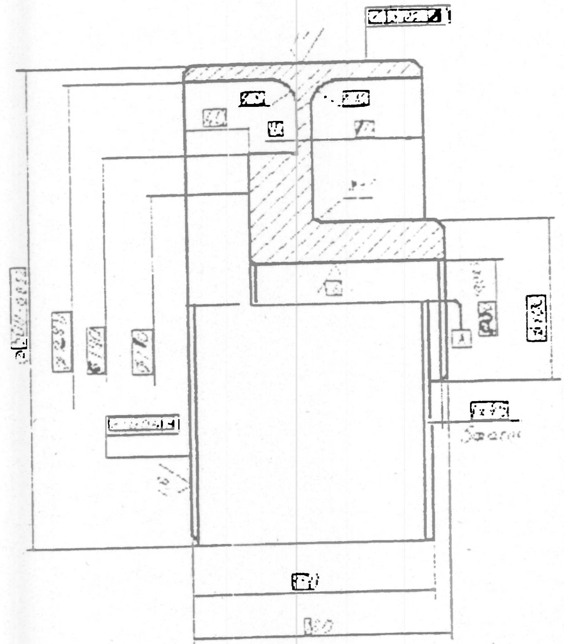

Fig.4d. Output image of the drawing after vectorization.recognition of graphic primitives.

7.Conclusion

In this paper, we considered the problem of MD image recognition. We extracted and described the main stages of the MD interpretation technology. The intermediate image models have been shown and described as well as the possible output image representations. Main principles of MD image interpretation have been introduced. Practical results of MD image interpretation are briefly described.

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