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1 Introduction

The problem of fast, precise, and inexpensive input of paper-based line drawings into computer systems is very important for many applications: engineering drawings could be represented in digital form for computer-aided design (CAD) systems; digital maps for geographic information systems (GIS); and diagrams for any systems working with graphical information. The problem of text recognition has attracted the attention of many researchers during recent decades. The text recognition systems currently being created allow fast input of textual documents and save much human time and effort. This growth in the development of text recognition systems leads to another very important application requiring graphic image interpretation: digital libraries, of which the input of various graphic documents such as text pages containing graphics, photographs, etc., forms an important part.

There are many applied areas where such systems could be used: digital maps for agriculture, ecology, geology, forestry, and defense; engineering drawings and diagrams for industrial enterprises; graphical documents for libraries, office automation, and information transmission. During last decades, image analysis community put much effort into developing systems for the automatic reading of various types of documents containing text, graphical information, pictures, etc. Information for such systems are usually input by scanners or cameras. These efforts were successful and now there are many systems for text/graphics recognition.

Another area that is closely–related but much more difficult, is the reading and understanding of line drawings, such as maps, engineering drawings, diagrams, etc. Many companies in the world work with cartographic information and computerization allows one to have a fuller access to information about our environment, that is up–to–date, following all changes, and saving human effort, time, and the money that would otherwise be expended performing these these tasks manually. That is why during the last decade, systems for document and line–drawing interpretation started to grow rapidly and now many organizations in Academia, and Industry work on this problem.

In this report, we consider a general problem of line–drawing interpretation and analyze German and Russian approaches to the problem. In the beginning, a comparison is made between manual and automatic line–drawing input, and between vector and raster types of information representation. To develop automatic input systems, document specifics are analyzed. A general methodology and requirements of document interpretation process is considered. We consider the basic technology stages and show how an initial image is transformed to a final representation. All intermediate image models are classified and described. Possible output image representations for maps and engineering drawings are considered. An overview of the existing Russian and German research systems and approaches is given as well as commercial systems existed at Russian market are considered. Analysis and comparison of German and Russian approaches is given. List of main conferences and publications in this area is shown. Finally, ways of West–East collaboration are considered.

2 Problem of Graphics Input

Since computers have come into general use , special tools and devices have been developed to digitize graphic information. Systems created in the 1970s were based mainly on manual input of graphics. They used manual (semiautomatic) digitizers, and the system operator had to trace lines or objects on graphic documents and input them into the computer. Text and other semantic information was input manually through the keyboard.

The process suffered from a number of drawbacks:

1. This procedure was slow, and inputting a single line–drawing map, for example, of size A2 or A3, involved many man–hours, sometimes numbering in the hundreds for large–size and complex line drawings .
2. During the manual digitization process, many errors were usually made, especially in the digitizing of object coordinates. It is obvious that it is practically impossible to extract object coordinates manually with an accuracy of, for example, 300 dots per inch.
3. The difficulties involved in object digitizing was tiring to the operator possibly damaging to the operator's vision.
4. The entire process required the employment of many operators and manual digitizers, making it very expensive.

In the 1970s, scanners began to be developed and used for inputting graphical information. The first systems based on scanners were mainly used to input text images. The principal benefit of using scanners is that they allow a fast transformation of an image from analog to digital form. Scanners allow a reduction in input time, but require highly developed software to interpret the results. Information obtained after scanning is represented in a digital raster form. The raster form of data representation (the raster image) is a matrix of defined size where each matrix element, or pixel, has its own value corresponding to its brightness. This image representation is not usually used directly in graphical information systems except for tasks such as information compression, storing, and transmission.

The output of such systems, to be suitable for further usage, should be in ASCII format for text representation, and graphics should be represented in a form suitable for CAD or GIS systems. These latter systems work mainly with vector graphics, where each primitive or object is represented by curves or points with vectors connecting these points. So, as one can see, there exist two main types of image representation: raster and vector. Let us compare these types with each other and consider their advantages/drawbacks.

3 Raster and Vector data

As it was written, raster image represents a matrix where each matrix element, or pixel, has its own value corresponding to its brightness. Vector representation means that objects are represented by curves or points with vectors connecting these points (Fig. 1).

Fig. 1: Example of an engineering drawing part in a vector form.

Raster data offers a number of advantages compared to the vector form of image representation [52]:

- a simple structure of raster data, i.e., a matrix of pixels;
- the direct visualization of raster data by means of a bitmap;
- the possibility of direct and fast drafting of raster data on raster plotters (without performing vector–to–raster transform);
- an improvement of accuracy determined by the scanning mode compared with vector data obtained after manual digitization of graphics.

Raster–based automatic technology of line–drawing interpretation allows:

- freeing of operators from the difficult job of manually digitizing line drawings, in particular the following of elongated objects;
- speeding up of the line–drawing digitization process, as scanning and vectorization are faster than manual line following;
- avoidance of many errors that result from manual line following;
- extension of the automation of the graphical input and design process;
- improved solution of many applied tasks in agriculture, industry, forest culture, cadastry, and other fields requiring digital maps and engineering drawings.

Many small companies working in computer science do not use graphical processing because the requisite manual input is an expensive process. Introducing automatic raster–based graphics input technology allows its more widespread usage.

On the other hand, direct use of raster data has a number of drawbacks that makes it difficult to use in applied systems:

- a large amount of scanned data is generated;
- logical object structure in the data is obliterated;
- difficulties in object extraction from the raster image compared to vector representation;
- object editing in the raster image is inconvenient.

Most of the existing CAD or GIS systems in use, like AutoCAD and ARC/INFO, work with the vector form of graphics representation. This means that the scanned raster data should be vectorized so that it can be used in these systems, making it suitable for further tasks.

The use of vector data has the following advantages:

- less volume of data compared to raster images;
- systems of vector data processing are usually cheaper than raster–based systems because they do not use peripheral devices such as scanners and raster plotters which, in the case of those required by large–scale line drawings , become quite expensive;
- systems and methods of vector data processing are already well–developed and used; most GIS and CAD systems are vector–based;
- vector data format is more suitable for representing spatio–logical relations between objects;

some of the calculation, searching, editing, and object extraction tasks are solved more simply by vector data representation than by raster representation.

At present, there exist commercial graphical input systems that transform information from raster to vector form. They are usually called image vectorization systems. Most of them produce a simple enough output description, and a digitized drawing is usually represented in terms of lines, arcs, and other simple primitives. To exploit the advantages of such systems, the output should directly represent well–known engineering drawing entities or cartographic objects.

Another peculiarity of existing systems is that they are usually oriented to one particular type of line drawing . It is evident that to recognize any type of line drawing, it is necessary to take into account all its specifics. For example, most of the developed map interpretation systems are concentrated on cadastral maps. However, there is a great need to digitize all types of line drawings, including other kinds of maps, engineering drawings, and diagrams.

Most of the existing systems for line–drawing interpretation are based on powerful work-stations or specialized hardware for processing large volumes of data. Such systems are expensive and suitable mainly for large companies. However, there is a niche in the market for systems based on lower specification machines (as IBM PCs).

One of the main problems in processing line–drawings is their size, which requires large memory capacity and computational power for storage and processing. The size of the scanned images can vary from 2550 pixels 3300 pixels for a business letter digitized at 300 DPI (12 dots per millimeter) to 34,000 pixels 44,000 pixels for a 34"44" E–sized engineering diagram digitized at 1.000 DPI.63 Scan resolution always trades off against time. At 200 DPI an E–Size drawing takes 8 megabytes of raw data. At 400 DPI it is 32 megabytes. At 1000 DPI, the minimum acceptable for graphics arts applications, it is 25 8 or 200 megabytes. At 2000 DPI, the best graphics arts resolution, it is 800 megabytes [63].

These large–size images are often divided into parts or frames that after vectorization are merged. An example of such processing is shown by Musavi et al [18] where a special coordinate system for image frames is used. Each image frame is processed individually and the resulting point data is converted to the universal coordinate system. The end points in each available frame are matched with the end points of adjacent frames. The point data is recorded to include lines that cross across one or more frames. The map can be reconstructed wholly if the data is scaled or in parts, but there are some difficulties in the processing of frame borders in this way and processing time is also increased due to the appearance of such additional operations as image partition and frame merging.

Another approach used to process large–size images is storage and processing, of a limited number of adjacent image lines (a stripe) in a special buffer, and moving this stripe across the image. In this case, only the image stripe is stored in computer memory, and images of any size can be processed, even in a restricted memory resource.

The third approach is to use coding techniques to represent the scanned image and then to process it. The main constraint in this case is that the processing techniques must work with the coded image (without decoding it), otherwise all the advantages of this approach will be lost. There are various image coding techniques like binary trees, quadtrees, MAT representation and others [40,48,64,75,76]. A powerful and popular technique for coding binary images is run–length (r–l) image representation, which can be easily obtained from a scanner. It is also appropriate for developing techniques for binary image processing. Example of line–by–line processing and skeletonization for interval codes is given by Piper [60]. Rutovitz [48] shows how a distance transform and mathematical morphology can be realized on r–l representation as well as using this representation for processing of gray–scale images.

4 Document Types and Specifics

In general, a document image analysis field includes different applied areas: processing of maps, technical drawings, technical pages, diagrams, recognition of text, text/graphics documents, ZIP codes, and others. Each applied task lends its own peculiarities in the interpretation technology. Technical pages are well known document types and we do not consider their specifics. Let us consider more detailed 2D line drawings such as maps, technical drawings, and diagrams. They have the following distinctions:

- large size (up to A0);
- mixed textual and graphical information (as opposed to text pages where graphics are usually placed in separate areas from text, we consider text symbols and graphic objects in line drawings, which tend to be mixed together);
- various object types (lines, symbols, and regions);
- objects that can be situated in different places in the line drawing, that can have different font and scale, and that can be rotated.
- the line drawing could be color, and its quality could be far from ideal, etc.

A decomposition of the line–drawing interpretation tasks is shown in Fig. 2.

Fig. 2: Decomposition of the line–drawing interpretation problem

Let us consider maps, engineering drawings, and diagrams in more detail. The following map types are usually considered and processed in such systems:

- cadastral maps;
- city maps;
- large–scale maps with a scale from 1:500 to 1:10000;
- map layers and color topographic maps with a scale from 1:10000 to 1:20000;
- survey geographic maps with a scale from 1:500000.

Many existing systems were developed and used for automatic input of information from large–scale maps (1:500 to 1:10000) with low density and little variety of information [2,12,14,15,50,55]. Solutions for interpretation of maps with medium scale (1:10000 to 1:50000), which have a high density and much variety of information, are mainly limited to the acquisition of single layers of information like road nets.

The cadastral maps are probably the main application of the automatic input systems. They have approximately the same view and object parameters in different countries: thickness of parcel borders, orientation of hatched lines to represent houses or administrative buildings, localization of text, etc. (Fig. 3). There is also a direct correspondence between objects in the image and objects in the real world they represent [42].

Fig. 3: Example of a cadastral map

Topographic maps are an important class of map image. They can be color or black–and–white, as shown in Fig. 4(a). Every country has its own rules for producing these maps, but in general every map contains three main types of objects:

1. lines with length much bigger than their width that have to be represented in output data base by their medial lines;

2. symbols that have restricted geometrical parameters and have to be represented by one or two points;

3. regions that have to be represented by their contours.

Another map type for input into the system is a map overlay. The overlay is a special form of a geographical map, with each layer displaying only one color (Fig. 4). Each layer is a black–and–white sheet that contains objects of one color on the original map. Following are the basic types of layers: road (yellow color on the original map), hydrography (blue color), forest (green color), isoline (brown color), and a layer containing objects of a black color.

A complete digital map (DM) is obtained by combining information from all the separately processed layers. Interpretation of topographic maps and map overlays is shown in Refs. [10, 19, 20, 25, 54].

Fig. 4: A map overlay with: (a) a common black layer, (b) a road layer, (c) a hydrography layer, (d) a forest layer, (e) a building layer, (f) an isoline layer.

Technical drawings or orthogonal projections represent planar views of 3D objects. The scanned image is usually made up of a set of lines with different thickness and symbols. One part of these lines (usually the thick lines) represents the projection on a plane of the contours of an object's section. The other part, often made by the thin lines and the symbols (characters, special annotations, etc.), is much more "linguistic" or symbolic, as it conveys the additional information necessary for full understanding of the drawing [42] An example of an engineering drawing is shown in Fig. 5.

Fig. 5: Example of an engineering drawing

Schemes and diagrams represent in a symbolic way electric circuits, printed board electronics wiring, the control flow of a program (flowcharts), the hierarchy in a company, etc. They do not usually represent details of real objects, but are rather a convenient way to represent the working principle of some device, program, or organization. Their main components are usually a set of symbols having a precise meaning, with links between these symbols represented by lines, and attributes given to the symbols and to the lines by text annotation or other symbols (Fig. 6) [42].

Fig. 6: Example of a flow–chart diagram

5 Methodology Of Line–Drawing Interpretation

It is clear that an ideal solution to the line–drawing image interpretation problem would be the complete automation of the expensive manual input and preparation of all of the information involved. However the current level of understanding of image recognition does not yet permit a fully–automated solution, i.e. solution without human intervention. The extensive research carried out to date, show that it is practically impossible to recognize line drawings automatically because they are designed to be read by humans, and include various object types with different fonts, orientations, sizes, etc. Therefore the main aim of graphical input system design is to minimize the human involvement.

This leads to the use of a combined technology of image interpretation which includes, automatic image vectorization and object recognition, together with interactive object interpretation techniques. Such a combination could allow an acceptable ratio between the quality and time constraints that will satisfy the customer's needs. Based on this, we introduce the following main requirements of 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 obtained objects, and entities should be used directly in CAD or GIS systems without further manual work. It is also desirable to obtain an output image description at as high a level as possible (blocks, high–level primitives, 2D and 3D objects).

2. Since no automatic solution to a line–drawing interpretation problem exists at present, the interpretation technology should be based on two parts: automatic image vectorization and automatic–interactive object recognition. The operator's job in the interactive part should be kept to a minimum.

3. Automatic image vectorization should provide a satisfactory vectorization quality, and fulfill appropriate time constraints. If the quality of the vectorized image is unsatisfactory (there are distortions, object defects, etc.) it increases the amount of work involved in interactive image editing, and all advantages of the automatic processing could be lost.

4. The 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 can be extracted from a raster image. The information lost at this stage could lead to incorrect object recognition and produce significant errors in the output.

5. Automatic object recognition techniques should be used wherever possible (i.e. where they give satisfactory results). They are particularly important for the recognition of elongated object areas, where manual input requires much time and effort.

6. For the recognition of objects, a satisfactory compromise should be found between automatic and interactive techniques, providing the minimum required processing

time, and maximum line–drawing accuracy. It should be decided in advance what objects will be recognized automatically and what objects will be recognized interactively.

7. The results of the automatic recognition stage should allow for both the simple correction of recognition errors, and the input of unrecognized objects. The interactive techniques should also be intelligent enough to treat not only points or segments, but also to input and recognize objects or substantial parts thereof. The interactive interpretation software should also be organized in such a way as to be user–friendly.

8. The time overheads in the entire automated process should be at least half of those involved in manual digitizing. This is a particular commercial requirement, as it is generally understood that automation can only be justified in terms of costs (new equipment and staff training) , when this condition is met.

9. The ability to interrupt the process at any processing stage and return to the previous stage is also required. If a processing stage, particularly an automated one, produces errors and distortions, it should be easy enough to recover the previous stage.

10. Digitized line–drawings should include the maximum possible range of object characteristics and, at the same time should be stored in the minimum possible data volume. The latter requirement is self–explanatory, the former requirement particularly applies to the problem of map processing, where it is nearly always better to have more objects and characteristics thereof, in the output database, so that they can be useful for further treatment.

11. The accuracy criteria of object representation (geometric coordinates) should always be met. Particularly in map digitizing, since deviations in the map object coordinates could influence further digital map treatment and usage.

12. The developed technology should be run on normal inexpensive computers (like IBM PC 486, Pentium, etc.). This will enable smaller enterprises to use them widely, and broaden the potential market.

6 Stages Of Line–Drawing Interpretation

In defining the main stages and forms of line–drawing representation during the interpretation procedure, we note that the processes involved can be considered as successive transformations of graphical information from one level of representation to a higher level of abstraction. The final aim is to generalize the data obtained from a scanner, to a suitable line–drawing representation for CAD or GIS systems [2,4,5,8].

From a general problem of automated conversion of line–drawings to CAD or GIS representation one can identify five principle 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 graphical primitives (segments);
3. recognition of the vector image model to obtain representations in terms of universal graphic elements: ED entities or cartographic objects;
4. understanding of the obtained image representation to acquire specific 2D or cartographic objects contained in CAD or GIS libraries with their parameters and relations;
5. complete reconstruction of 3D engineering objects or the 3D digital terrain model with all "semantic" attributes.

According to these stages, let us introduce the following basic types of line–drawing image models:

Mi	initial line–drawing;
Mr	raster model represented as gray–scale (Mrg) or binary image (Mrb);
Mv	intermediate vector model which includes the description of the image in terms of graphic primitives;
Me	vector image description in terms of ED entities or cartographic objects;
M2D	applied model containing image description in terms of 2D objects.
M3D	image model in terms of 3D objects.

So, the process of image interpretation, in a general case, means a sequence of technological stages:

$\text{Mi} \Longrightarrow \text{Mr} \Longrightarrow \text{Mv} \Longrightarrow \text{Me} \Longrightarrow \text{M2D} \Longrightarrow \text{M3D}$

In principle, the result of each task solution 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 GIS or CAD systems, but will require a long time and some human interaction to create the required digital models for an ED or map. To be a useful system practically, it should supply the main, high–level entities defined, for example, by Initial Graphics Exchange Specifications, or cartographic objects supported by the Cartographic Classifier. Therefore the correct solution of the third task must satisfy industrial requirements.

A universal solution for the fourth task of identifying ED entities and/or cartographic objects is a very difficult objective, however its solution for particular cases is less complex. The incorrect performance of this fourth task can significantly increase the required quantity of interactive image editing. Moreover, it is very closely connected with the fifth task, because many modern CAD systems operate with complex 3D objects which can only be recognized after the analysis of all orthogonal projections, and even isometric pictures. But the fifth task is more concerned with geometric modeling.

It should be noted that each one of these tasks or stages includes many sub–stages in transforming an image from one form to another. Most of these sub–stages will be considered in detail below.

7 Image Representations

According to the above scheme of the line–drawing interpretation process, there are the following main levels of image representation: an initial line–drawing, a raster image, an intermediate vector image model, image representation in terms of universal ED entities or cartographic objects, 2D and 3D image representations. As mentioned, the later stages and their results could be used as final outputs of the process and thus are considered separately. The initial line–drawing and its types have been considered and described above.

7.1 Raster image

It is assumed that the scanned image is represented in a binary format, and the thresholding operations has already been done by scanner or by software. If, for some reason, a binary image does not yield sufficient information, the scanned image should be represented in a gray–scale form. The underlying notion of this kind of image is a connected component (CC) which represents a connected set of black pixels.

The raster image is represented in three main forms: in an original form obtained after scanning where all objects are usually thick (Fig. 7a); a contour form where all objects are represented by their contours (Fig. 7b); and in a skeletal form where all objects are represented by their skeletons (Fig. 7c).

7.2 Vector image representation

This level is the result of the vectorization process. It contains the description of the connected components and/or their subparts. Such a level of ED representation is presented in two forms: contour and skeleton.

Contour form

The Contour form (C–form) of the vector image is obtained from the contour raster image and contains a description of object contours in a vector form. This form is usually far from being the required output representation, however it is often considered as auxiliary information for further recognition processes, because some elements of the ED can be easily extracted from it.

Skeleton form

The skeleton form (S–form) of the vector image is obtained from a thinned image and contains the two main data types for further recognition. They are segments (vectorized CC parts of a thinned image bounded by end and node points) and nodes describing connections between segments. This form is more structured than the previous one and is used as a basis for further image recognition. It contains detailed information not only about the location of segments but also useful data about their characteristics and relationships. Additionally, this form also includes information about segment curvature (polyline, straight line or circular arc).

Primitives form

Vector image representation in terms of graphic primitives (P–form) that is mainly obtained from the S–form. Examples of simple graphic primitives are lines, arcs, characters, conics. Complex graphic primitives include text strokes, dashed lines, lines with different thickness, etc.). Examples of some graphic primitives are shown in Fig. 8.

Fig. 8: 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.

Generally, this form could be used as an output for solving applied tasks, although it does represent quite a low level of abstraction. It is also suitable for the image storage problem. In this case, the archive volume is decreased, and the data more closely resembles the native form used in CAD systems, compared to simple vector image representation (described above).

8 Possible Outputs

From a simple vector form, the image is further transformed into a more complicated form that already could be used as the output of a line–drawing interpretation system. At each subsequent level of image representation, higher levels of abstraction are achieved. We can identify the following levels of line–drawing image representation:

- in terms of ED entities for CAD systems and cartographical objects for GIS systems;
- in terms of 2D objects;
- in terms of 3D objects.

Movement from one level to another provides higher levels of abstraction, suitable for CAD or GIS systems. These levels in are now considered in more detail.

8.1 ED entities form

The ED entities form (E–form)represents the contents of the drawing in terms of particular entities, which reflect some semantic part of ED. They include contour lines, symmetry axes (represented by dash–dotted lines), hidden contour lines (represented by dashed lines), material areas (represented by crosshatchings), dimensions (thin lines with arrows, witness lines and so on), annotation text, etc.

The ED entities could also be separated into simple and complex ones. Simple entities are combinations of the graphic primitives (or their component parts) and are used to represent simple elements like a symmetry axis, a crosshatching line, the border of material area, etc. In some cases, the simple entities can coincide with primitives but in generally they are more complex (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 ED structures — scenes — and can be presented as combinations of graphic primitives and a set of other simple and/or complex entities. Examples of such entities are crosshatched areas (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 ED entities are shown in Fig. 9.

Fig. 9: Examples of ED entities; simple entities: (b) symmetry axis, (d) border of crosshatching area; complex entities: (a) dimension, (c) crosshatching area, (d) a set of concentric circles.

The ED entities can be used as a basis for understanding the whole image, i.e. for extraction of 2D objects according to particular area of interest with the corresponding CAD library (for example, gear–box, shafts, screws, etc), and/or for the problem of 3D image model reconstruction.

Concerning data representation the formats for storing the recognized graphic primitives and ED entities are analyzed in Section 8.3.

8.2 Map representation in terms of cartographic objects

To interpret an object on a map drawing, it is necessary to determine its three main parameters: its type, its geometry, and its semantics. In general a cartographic object should be represented in an output database by this information. Figure 10 shows examples of cartographic objects.

Fig. 10: Examples of cartographic objects: a) roads, b) buildings, c) isolines, d) – e) rivers.

An object type is determined by its graphic representation on the image and implies a real object, or object class, on the map drawing. Classifying objects by type is an ordinary pattern recognition task.

The geometry (object coordinates) is determined from the object's position on the image, and will be different for different object types. Line objects are represented by their skeletons, symbols by one or two points, and regions by their contours.

The semantics reflect some of the characteristics (geometric, constructive and others) of the real terrain object by an appropriate graphical pattern on the map. It can be determined in two ways: (1) by its graphic representation (structure, color, etc.) of the object; (2) with the help of special conventional signs and symbols (signatures, texture elements, etc.).

8.3 2D object representation

Probably a more desirable output of engineering drawing interpretation that could be directly used in CAD systems consists of in extracting 2D objects specific for a concrete applied domain. Examples of such objects are gear–boxes, shafts, screws of mechanical devices on engineering drawings. These objects could be recognized from the ED entities extracted at the previous stage. The recognition algorithms must take into account all specifics and knowledge about the problem domain. Examples of recognition of some 2D objects are given in Refs [31, 69].

8.4 3D object representation

Ideally, the final aim of the engineering drawing interpretation should be in constructing 3D objects for their further use in CAD/CAM systems. To perform this task, three or more projections of engineering drawings should be considered. Each projection is a separate ED having features that are visible from the corresponding viewpoint. Usually, in many engineering drawings only the standard six orthogonal views (front, top, right side, left side, back and bottom) or some subset of these are used. The task is to combine all these views and construct a 3D object from these projections. The final 3D object representation could be considered as is required by CAD/CAM system. The mathematical tools usually used for this kind of representation include spline functions, polynomials of higher orders, etc.

In spite of the fact that 2D or 3D object representation would be a more desirable system output, it can not be achieved automatically from an initial line–drawing with the existing state of image processing and pattern recognition theory. That is why the output of line–drawing interpretation used in most of the systems is a description of line drawings in terms of graphical primitives, and ED entities (for engineering drawings) or cartographical objects (for maps).

The interpreted line–drawing should be represented in some format and recorded in an output data base. There are known many formats and standards to represent spatial information from line–drawings. The first formats were task oriented and used for concrete tasks and problem domains. Examples of them are American formats DEM, DLG, GBF/DIME, TIGER. The formats developed in 80s like SDTS, SAIF, NTF became more universal. The universal formats are characterized by their possibility to represent and transmit any type of spatial data without loss of information. However, they are quite complicated and difficult for data exchange.

Probably the most famous and more often used are DXF and ARC/INFO Generate/Ungenerate formats. After them, such formats as MIF/MID MapInfo, ArcView SHAPE File, Atlas BNA and some others follow. One of the biggest and more developed format is probably American standard SDTS. There are its variations in other countries like ASDTS in Australia. This format allows one to store most of the spatial data types including vector and raster data.

VPF standard (Vector Product Format) as a standard of USA Ministry of Defense has been introduced in 1992. It is oriented on storing of large geographical data bases, independent on computer platforms and allows one to store most data types. In this format, DCW (Digital Chart of the World) has been created.

For representation of vector data, the most popular are DXF and ARC/INFO Generate/Ungenerate formats. Converters from DXF format exist in practically all of developed systems. If it is necessary to represent an attribute data, the formats DBF and CSV are probably the best ones.

A brief scheme describing the introduced image forms and its connection in the ED interpretation process is shown in Figure 11.

9 Systems Existing at the Russian Market

9.1 Commercial Systems

In the mid to late 1980s, document image analysis began to grow rapidly as hardware development allowed the processing of images within reasonable cost and time. Commercial document analysis systems are now available for input, recognition, and storage of some business and financial forms, printed and partially handwritten text, and for compression and transmission of line drawings.

At present, there are many systems, including commercial ones, that perform a conversion of scanned raster images into a vector form. However, most of them are restricted by a vectorization of raster data to obtain an image description in terms of simple graphic primitives and do not allow the higher–level description needed, for example, for CAD or GIS systems. The scanned information is usually a black–and–white (sometimes a gray–scale) image represented in such formats as TIFF, GIF, VIFF, PMB and others. The output often consists of quite simple primitives like lines, polylines, arcs, circles, dots, squares, and rectangles. As output formats, DXF, ARC/INFO Generate/Ungenerate, MIF/MID MapInfo, ArcView SHAPE File, Atlas BNA, and SDTS formats are the most popular. Practically every system includes a set of interactive techniques to edit, rectify, and enhance images.

Below we show the vectorization systems that are available in the Russian market [41]. As one can see from Table 1 there are many systems in this market, which can be explained by two main reasons. The primary development of GIS technologies in the United States and Western Europe occurred at a 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 frequently base map digitizing and updating on remote sensing images obtained from satellites. In Russia, the interest in GIS technologies developed more recently when scanning technology and scanners became inexpensive and more widely available. 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.

9.2 Line–drawing interpretation systems

From research Russian systems of line–drawing interpretation we consider the systems developed by the groups leaded by Prof.M.Schlesinger (Kiev, Ukraine), Prof.Yu.Vasin (Nishni Novgorod, Russia), Prof.S.Ablameyko (Minsk, Byelorussia), and Prof.S.Sadykov (Tashkent, Uzbekistan).

The system TEREMKI developed by M.Schlesinger et al in Institute of Cybernetics, Kiev [102, 103] is devoted for fast vectorization and recognition of engineering drawing and integrated circuit images. The process is based on the idea of fast movement from raster to vector form of line–drawing and do not storing raster image in computer memory. It includes two stages: image vectorization and primitive/object recognition. The vectorization stage is based on the introduced notion of "corners" that allow very fast vectorization of rectangular–shaped objects and lines with right angles. In a result, corners of lines are extracted and lines are approximated preserving the corners. Recognition of some primitives have been also performed.

A range of systems with name "Raster" has been developed in N.Novgorod State University by Yu.Vasin et al [104]. They were mainly developed and used system to digitize large–format color and black–and–white Russian topographic maps of scale 1:25000–1:200000. Together with image vectorization, recognition of some cartographical symbols were made. The systems are intended to digitize large–format color and black–and–white Russian topographic maps and are successfully used in many Russian enterprises.

Approaches and systems to interpret line–drawings have been developed by S.Sadykov et al in the Institute of Cybernetics, Tashkent [105]. To extract features of line–drawing objects, they developed an approach based on distance transform of line patterns. Recognition of several symbol types have also been performed.

Institute of Engineering Cybernetics, Minsk has a big experience in developing map digitizing systems [13,17,19,20]. To input documents into computer, we use a colour large–format scanner developed in our Institute. It has the following characteristics:

- scan area: 680x510 mm;
- resolution: 25, 50, 100 mkm;
- scanning modes:
  - binary: one bit per pixel
  - colour: one byte per pixel

Scanning of the colour map of scale 1:50000 is performed by 30–40 min with simultaneous extraction of 5 colours in one pass. The data are divided into different files corresponding to each colour and are recorded to hard disk.

To store and process scanned binary images, we use a modified run–length image representation obtained from standard TIFF, PCX, MSP formats. We assume that each of the preprocessing tasks can be solved using the same principles because the result of any operation implementation with regard to any line is fully determined only by few adjacent lines. These line stripe is stored in a specially reserved buffer. Each program has access to all of these lines and can check and change their pixels using some basic techniques. The lines of the stripe are processed from bottom to top. The stripe moves consequently on the whole image from top to bottom, and all operations are performed during this move. Therefore, after every inspection of the stripe the corresponding operation is fully executed for the top line stripe. This line is removed from the stripe and a new bottom line is introduced.

To process all line–drawing image types, the following variants of r–t–v have been developed:

1. Line–like image vectorization that produce a skeleton description of objects and symbols.
2. Region–like image vectorization that produce a contour description of objects.

For representation of processed images in a vector form, we use three–level image representation. First level contains the information about connected components and their characteristics; second – about segments with characteristics; and third – about feature points and their arrangement. A detailed description of these algorithms and levels is given in [13,93].

Special techniques have been developed for recognition various object types namely for recognition of isolines, roads, forests, and symbols. Such as it is practically impossible to recognize all cartographical objects automatically, we developed and use interactive technology of map interpretation. It represents a modified automatic object recognition performed under an operator control.

The result of map digitizing is recorded in a cartographical data base. The data base was realized on a basis of relational model and consists of three files: file of metrics, file of characteristics, and inquiry file [17]. The inquiry file contains the following information about object: classificational code, relationships with other objects, references to metrics and semantics. The file of metrics includes a geometrical object coordinates. The file of characteristics contains an information about object characteristics.

The existed experience has been successfully applied for interpretation of ED images [47]. The vectorization process for ED and map images is similar, although it has some small differences. The recognition stage is aimed at obtaining a representation of an ED image in terms of universal ED entities: arcs, circles, line types, blocks, crosshatched areas, dimensions, and others. To recognize ED entities, we develop a technology which is based on the following principles:

1. The first principle – "from simple to complex" – determines a sequence of the ED elements recognition and forming of output database. It consist in that the ED is recognized starting from the simple graphical primitives and moving towards the more complex CAD entities. For example, recognition of dimensions – more complex recognized elements – is performed after recognition of all other entities; in this case, we do not check many "false" variants as we have maximal information about ED contents.
2. The second principle defines rules for checking and advancing of hypotheses for ED entities recognition. It consists in a maximal usage of space–logical relations

between elements of different forms of data representation. The majority of such space–logical relations (crossing, crossing under defined angle, joining etc.) are informative enough and can be used to advance hypothesis about presence of some new primitive or CAD entity on the image. The space–logical relations are always fixed and used when it is possible during the recognition process.

3. The third principle – "from local to global analysis" – defines rules of complex entities recognition. It consists in a sequential complication of recognition techniques. The point is, that on the first steps of ED recognition, when a little amount of additional useful information exists, it is very dangerous to continue recognition of any graphical element under some contradictory conditions, because a mistake in such doubtful situation can leads to unpredictable results. So, we introduce two stages of ED graphical elements recognition. On the first stage, under "information hunger" condition, so called "clean parts" of corresponding elements are extracted using only local analysis of situations. On the second stage, we try to resolve every doubtful situation by means of more complex and not so dangerous in a given moment global analysis.

4. The fourth principle consists in maximal available taking into consideration of engineering drawing specifics. Using this principle we try to extract all the useful information about some parts of CAD entities on the earliest stages of ED processing (before recognition). After recognition, we must use peculiarities how the ED graphical primitives are drawn on the document and how they influence one to another.

The system has been developed on IBM PC/AT computer in C language. The input engineering drawings are usually digitized with a resolution of 20 pixels per 1 mm and 300 DPI. The raster data are represented in PCX, TIFF or MSP format. Output data are represented in the IGES or AutoCAD DXB, DXF files. 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 ED elements are aligned and transformed to DXF AutoCAD format. The performed experiments show enough good quality and noise stability of recognition.

9.3 Text recognition systems

Then, we show some of our results for text and form recognition. One of the successful solutions in this area was creation of reading machines to recognize various types of forms.

Works in form recognition have been started in Computer Research Institute, Minsk more than 30 years ago. In 1966, the first optical reading machine "Blank" has been created and results of 1969 All–union census has been processed by using this machine. Various machine modifications have further been developed and used for different applications:

USSR censuses in 1979 and 1989 ("Blank–3", "Blank–6"), input and processing of USSR Communist Party documents ("Blank–4", "Blank–5", Blank–7") and others.

Let us consider characteristics of several developed reading machines. "Blank–6" machine was used for USSR census in 1989 and had the following characteristics [80]:

- rate of reading: 150 documents/min;
- capacity of pockets:
  - feeding pocket – 700 forms;
  - first receiving pocket – 700 forms;
  - second receiving pocket – 100 forms;
- form size – 210x297 mm;
- recognition vocabulary – 10 digits and special symbols;
- machine size – 1600x1320x550 mm.

"Blank–7" (developed in 1988) machine productivity is 400 documents/min. Starting form 1994 a new big project funded by Russian government was began to develop a reading machine "Blank–9" for 1999 Russian census. It represents a A4 scanner with resolution 300 DPI with automatic feeding of documents, productivity – 20 documents/min.

A system "Passcan" has been developed by Belarussian company "Optics–Electronic Systems for reading national passports. As known passports have a special zone at the last passport page for computer reading and recognition of its owner. The system "Passcan" represents an optics–electronic scanner which allows reading and recognition of machine–reading passport zone made in ICAO standard. Scanner performs zone reading and its adaptive binarization. The recognition algorithm is based on combination of structural approach (for classification of symbols) and zond approach (for symbol recognition). The "Passcan" system characteristics are the following:

- one recognition mistake for 50 000 symbols;
- one refusal for 5 000 symbols;
- recognition time – 4 sec for all zone;
- scanner size – 180x150x60 mm;
- weight – 0,8 kg.

The system called ADRES (Automatic Document REading System) has been developed for recognition of text pages with Latin and Cyrillic alphabets [114]. It supports different text fonts and various scanners. The last version of the system has been realized in

Microsoft Windows for IBM PC computer. The used for text recognition method is based on structural approach and is modified to take into account all specifics of text pages . Recognition time is about 1 minute for 1 page. The recognition reliability depends from a text page quality and reaches 100has a vocabulary inside it that allows automatically check quality recognition and correct recognition mistakes that increase a recognition reliability.

We refer two systems for recognition of handwritten text.

1. Manuscript – recognition of handwritten text for identification of person by using his/her handwriting [113]. All information for the systems are input from a scanner. The system is based on analysis of two handwritten texts and take a decision if these two texts belong to one person or not. The system builds a mathematical model of a text basing on analysis of stable features of handwritten text. It allows also to recognize different variations of a text written by one person. Average time needed to make a conclusion for the system is about 30 seconds with the same reliability as an expert.

2. SignInspector – analysis of signatures for verifying and confirmation of document authentics by using person's signature [113]. The SignInspector system is developed for banks, customs, etc. where it is necessary to identify personality based on his/her signature. It has approximately the same mathematical tools like previous system adapted for some signature specifics. The systems have been realized in Microsoft Windows for IBM PC 486 computers. These both systems are now under testing with several Police organizations.

If document contains mixed text and graphics information, it should be separated in the beginning. To solve this task, we developed text/graphics separation algorithm based on two simple and standard properties of technical paper pages. We call them as area and text compactness properties. The area property takes into account the geometrical relationships between text and graphics. The text compactness property reflects the spatial relationships between text components within block and between text and graphics. An application of both properties allows to accurately perform the separation in the cases above. No skew correction is required before separation and text and graphic blocks can have arbitrary shape [79].

10 German Systems

10.1 Line–drawing interpretation systems

Germany has several strong groups that develop full systems for line–drawing image interpretation as well as many groups working in document recognition and in various close related areas solving particular tasks in binary image processing and pattern recognition. Let us consider in the beginning, the developed German line–drawing interpretation systems.

The PROMAP system has been developed by Lauterbach et al [25, 54] to digitize German topographic color maps on a scale of 1:25000. The maps are scanned with a 24–bit red, green, and blue scanner and are separated into four main layers. Symbols and objects are recognized at a raster level and further vectorization is performed. Region–based layers are vectorized by a contour tracing algorithm, and line–based layers are thinned by using a smoothing and stripping technique. The vectorized image is represented in a vector form that is based on nodes and vertices.

A unique feature of PROMAP is its strong use of knowledge for image interpretation. An associate net is used as knowledge representation scheme. The basic structure of the net is the data structure concept. An intentional description of the concept is given completely by necessary parts, structure relations and attributes. The model includes declarative knowledge as well as procedural knowledge.

A system Drawing Capture and Recognition (DCR) has been jointly by Fraunhofer–Institute for Production Systems and Design Technology (IPK), Berlin and University of Hamburg [78]. The system allows one to process poor quality of engineering drawings and maps and transform them into CAD files. It includes the stages of binarization of gray–scale images, binary image skeletonization, recognition of graphical primitives like straight lines, circles, arrows, and filled areas. Text is separated from graphics. Then, postprocessing is performed that allows one to improve results of graphical primitive recognition. Finally, 2–D interpretation is performed that includes recognition of dimensioning and some other objects.

A system for the interpretation of scanned cadastral maps has been developed by Mayer, Heipke and Maderlecher [116]. They apply their approach to binary images of 1024×1024 pixels which result from scanning and preprocessing 1:1000 and 1:5000 cadastral maps at a resolution of 400 dpi. The processing consists of four levels which reach from the binary raster image to a level of semantic objects. After thinning, the binary image is vectorized and the resulting lines are combined in a data–driven way to image graphs which constitute the second level. By the size of these graphs text and cadastral symbols are separated from graphics. These parts are analyzed in a highly data–driven way. For the recognition of text and symbols the OCR–system is used. The implementation is realized using common LISP and CLOS. The approach uses a combination of data–driven and model–driven techniques with a strong emphasis on the model–driven part.

The MERLIN–system (Maschinelle Erfassung und Interpretation technischer Linienzeichnungen, *machine registration and interpretation of technical line–drawings*) has been developed by Th. Bartsch et al. in order to provide a system that converts binary raster images of technical drawings into drawings which is usable in a CAD system [117]. The system has been implemented prototypically in C++. After vectorization After vectorization the recognition of all kind of symbols from text to contour and crosshatchings is realized using the character description language (CDL). This approach is orientation– and scale–invariant. In a subsequent step the geometry of the drawing is adjusted according to the measures given within the drawing. In this phase an intervention by the user is possible. Finally MERLIN performs a knowledge based 3D reconstruction, which is usable within a CAD–system.

Pasternak and Sprengel proposed an universal specification of geometrical knowledge, which is not restricted to a special field of application [118]. The system starts off with a vectorized image and takes the primitive elements of the vectorization as basis elements for the geometric specification. The specification is performed in a way to separate a form–specification, which does not depend of the place in the image or the orientation, from the specification for the position of an element in the image.

10.2 Document recognition systems

Germany has also a strong records in developing document analysis systems like for example analysis of text or text/graphics pages. A system called ANASTASIL developed in German Research Center for Artificial Intelligence (DFKI) by A.Dengel is intended for low–level and high–level geometric analysis of printed documents [107]. The system identifies important conceptual parts (logical objects) within business letters like recipient, sender or company specific printings. The recognition algorithm is based on geometric knowledge sources like global geometric knowledge about logical object arrangements, and local geometric knowledge about formal features of logical objects. The system has been developed at SUN 3/60 workstation and Macintosh.

A system for recognition of printed documents has been developed in Daimler–Benz Research Center, Ulm by T.Bayer, J.Franke et al [106]. It is intended mainly to process printed text documents like text pages although many its tools could be applied for recognition of handwritten patterns, graphics and photographic data. The developed algorithms process iconic data, generate simple symbolic primitives (like connected components), create more structural ones (like words, lines and text–blocks), and deduce the meaning of primitives (as the character classifier does). The system is permanently developed and applied to new problems.

The system CRIPT for recognition of compound–organized text permits to analyze text images having compound structure with different distortions: considerably skewed text, crooked text lines, numerous noise, fractured and touched characters, multicolumn text with multilevel hierarchy, text with illustrations, multilevel formulae, tables and graphics. The structurizer is based on fast algorithms of hierarchical cluster–analysis and uses bottom–up and top–down approaches.

Except of the groups developing full line–drawing interpretation systems, a lot of research is doing in the area of binary image processing and pattern recognition with possible application of the techniques to line–drawing image processing.

A contribution to low–level binary image processing has been made in Hamburg University (Prof. U. Eckhardt) together with Siemens AG, Munchen (Dr. G. Maderlechner) [110, 111]. There were studied structure of object boundaries and conditions for parallel reduction of digital sets that led to an invariant thinning algorithm that has been applied to thin document images. It has been shown that the proposed algorithm has theoretically favorable properties, e.g. it is invariant with respect to translations, reflections and rotations. The proposed method was designed as a parallel method although it is also very efficient when applied sequentially. Due to its invariance, the skeleton obtained by this method does not depend on the specific implementation of the algorithm.

Strong contribution is made in low–level binary image processing and digital geometry by group of scientists from Hamburg University (L.Latecki, C.Conrad et al). They define main conditions that guarantee a digitization process preserves an object topology [108, 109] that is that a real object and its digital image are topologically equivalent.

11 Analysis of the Approaches

Analyzing German and Russian approaches to line–drawing recognition we must say that they are quite similar. Let us note in the beginning similarities of the approaches and then we will show differences.

The Russian and German approaches are similar in that they generally could be separated into two main stages: image vectorization and object recognition. However, such as line–drawings belong to complicated image type, they cannot be interpreted fully automatically. The existing map interpretation systems can only automatically recognize simple maps. To digitize all main map types, the combination of automatic and interactive techniques is usually used. The maps can be scanned and automatically vectorized, however the object recognition, correction and forming of output representation stages is usually made in an automatic–interactive mode. Such an approach allows one to minimize the quantity of digitization errors, decrease the time of the digitizing process, and reduce the complexity of an operator's work in comparison with completely manual digitization. Compared to fully automatic image recognition, it allows the digitization of complex objects under operator control, instead of automatic object recognition, with manual error correction. An acceptable ratio between quality and time, and the extent of the digitization can be reached

For processing of colour topographic maps both approaches are based on splitting of the scanned image into separate layers. In this case, after the processing of map layer an entire digital map (DM) is obtained by combining information from all the separately processed layers. The used sequence of layers processing is also similar because it goes from processing of simple layers to complex ones. In Russian systems, the most effective sequence of map overlay interpretation is the following: firstly, map layers containing area objects are processed, then isoline and hydrography layers, and finally the black layer is processed. This suggested sequence allows one the use of information from the previously processed layer, to interpret the next one. For example, after the road layer has been recognized, its information is used to identify road objects and their characteristics on the black layer.

Knowledge about maps, objects, and their specifics are usually used as much as possible in both approaches. When a map is produced, some special rules and conventions are used which define object and scene representation. There are two main benefits from using this kind of knowledge:

- it allows the increase in the extent of automatic object recognition one is able to perform;
- it is useful in making the system more general for the processing of various types and scales of maps.

Both approaches try to make information and knowledge about objects and map specifics independent on recognition algorithms. This means that if new maps are to be processed, the recognition algorithms should not be changed, only the cartographic knowledge and data. It will allow to process maps of different types and scales in a system without significant changes in software.

The main difference between German and Russian approaches is that Russian systems usually try do not perform any operations with raster images except their vectorization such as some German systems for example PROMAP perform recognition of symbols and some objects at taster image. It is explained by the fact that Russian computers were always not powerful and it was very difficult to store and process large–size raster images in a small computer memory. That is why Russian approaches were in immediate vectorization of raster images and then analysis of vector image representation to recognize the vectorized objects.

This circumstance (powerfulness of computers) led to some difference in approaches to image vectorization and object recognition. Russian systems usually did not work with gray–scale images performing binarization inside of a scanner and working with binary level as with initial images. German as well as some other systems get a gray–scale image after scanning, analyze and binarize them and then perform image vectorization.

The vectorization techniques developed in Russian systems were based on storing of minimal amount of image lines or image information into computer memory and performing image vectorization operations with these lines. German systems that are based on more powerful computers store a full raster image into computer memory and perform various vectorization operations as well as recognition of some object types at raster images.

The last circumstance leads to different approaches to object recognition. Russian systems use mainly structural approaches for cartographical object recognition such as German systems together with structural approach use also approaches oriented on raster image representation, for example category–specific algorithm in PROMAP system.

12 Some Research Systems in Other Countries

Here, we shortly describe the developed system to recognize map and engineering drawing images.

The ANON system for ED interpretation was developed by the English scientists Joseph and Pridmore [62] and is based on the combination of schemata describing prototypical drawing constructs with a library of low–level image analysis routines and a set of explicit control rules. The system works directly with raster images without prior thresholding and vectorization, combining the extraction of primitives with their interpretation. Bottom–up and top–down strategies are integrated into a single framework.

The CELESSTIN system developed by the French scientists Vaxiviere and Tombre[44] uses high–level knowledge for interpretation of mechanical drawings. The CELESSTIN system uses the following knowledge rules: technologically significant entities are extracted and the whole setup is analyzed with respect to disassembling and kinematic knowledge. The last version of the CELESSTIN uses knowledge rules relative to the semantics, i.e., to the functionalities of the recognized objects and not only the representation rules.

A number of systems for interpretation of line drawings was developed by a group of American scientists lead by R. Kasturi that is described in Refs. [9, 28, 45, 63]. Algorithms were developed for text/graphics separation, recognition of arrowheads, tails, and witness lines; association of feature control frames and dimensioning text with the corresponding dimensioning lines; and detection of dashed lines, sectioning lines, and other objects. The systems have been applied to interpret maps, engineering drawings, and telephone system manhole drawings.

The REDRAW system was developed in France by Antoni et al. [1] to interpret mechanical drawings and maps. It uses a–priori knowledge to achieve interpretation at a semantical level and is based on a model–driven system that can be completely parameterized. A priori knowledge about the domain induces a particular interpretation process for each document class. Parallel lines are among the recognized objects.

A system to recognize engineering drawings and maps developed by a group of Japanese scientists lead by M.Ejiri [14] is based on color and monochrome automatic digitizers. In these digitizers, lines and figure contours are automatically coded as a set of vectors, each consisting of a pair of point coordinates. Automatic recognition of line types, overlapped lines and wires, map roads, characters, and symbols is performed. This system has been used to recognize urban and utility maps, LSI cell diagrams, and logic diagrams.

The MARIS system developed by Japanese scientists Suzuki and Yamada [10] is used to digitize large reduced–scale maps of Japan. The MARIS vectorization method is based on border tracing and line tracking algorithms. The vectorized image is represented in a vector database and objects are further recognized. Interactive editing and correction of misrecognized and unrecognized objects are further used. The system permits the accurate digitization of three layers: building lines, contour lines, and lines for railways, roads, and water areas.

A system to automatically extract information from paper– based maps and answer queries related to spatial features and structure of geographic data was developed in USA by Kasturi et al. [9,34] Algorithms to detect symbols, identify and track various types of lines, follow closed contours, compute distances, and find shortest paths have been realized in the system. The developed query processor analyzes the queries presented by the user in the predefined syntax, controls the operation of the image processing algorithms, and interacts with the user.

A system for automatic input and recognition of Italian land register maps was developed by Boatto et al. [15] This system uses the semantics of land register maps extensively to obtain correct interpretation. The final graph image representation provides a formal description of image topological and metrical properties that is stored in a database. The system requires the operator to resolve ambiguities and correct errors in the automatic processes.

A system for robust recognition of drawings superimposed on maps was developed in Japan by Shimotsuji et al. [7] In the beginning, graphic and character regions are decomposed into primitive lines, the definition of which includes their orientation and connectivity with other lines. Objects are extracted from these primitive lines based on recognition techniques that use shape and topological information to group them into meaningful sets such as character strings, symbols, and figure lines. The system was applied to recognize equipment diagrams superimposed on a map.

This brief overview shows that there exists a wide spectrum of systems and technologies for line–drawing interpretation, which can be classified by the following criteria:

- fragmentation (F) of line–drawing images into parts or processing a whole sheet (S);
- storing an intermediate vector model for a whole image (Mv) or object recognition from a raster image (Mr);
- types of intermediate vector image representation for its recognition: contour (Mvc), thinned (Mvt) or mixed–image representation (Mvm) containing contour and skeleton object representation;
- types of objects recognized at the systems;
- types of used computers.

The classification of some known systems in accordance with this scheme is given in Table 2.

13 Conferences and Journals in Document Recognition

Historically, the line–drawing interpretation problem has its roots in optical character recognition (OCR) tasks. Characters were the first patterns for which recognition algorithms were developed. Thousands of papers and many books have been devoted to this problem. OCR methods were a base for document analysis systems where documents are various text pages, special forms, etc.

On the other hand, the development of binary image processing area in the 1960s–70s has contributed much to the line–drawing interpretation problem. Such binary image processing techniques as thinning, contouring, and vectorization are the main stages in line–drawing interpretation technology. A comprehensive bibliography can be found in Refs. [16, 37, 42, 61, 63].

At present, there are many published papers devoted to recognition of document or line–drawing images. A number of books devoted to this problem have been published in the past year [63, 65–72, 76]. In the 1990s, special issues of international journals devoted to line–drawing interpretation have appeared. The description of many systems and methods for this task can also be found in the Proceedings of the following conferences and workshops:

International Conference on Document Analysis and Recognition (1991, 93, 95);
International Workshops "Machine Vision Applications" (1988, 90, 92, 94, 1996);

International Workshops "Document Analysis Systems (1994, 96);
International Workshops "Graphics Recognition" (1995).
Symposiums on Document Analysis and Information Retrieval (1992, 94, 96).
SPIE Conferences on Document Recognition (1992, 94, 96).
International Workshops on Advances in Structural and Syntactic Pattern Recognition (1990, 92, 94, 96).

Special issues of Computer Magazine (July 1992), Machine Vision and Applications journal (1992, 1993), International Journal of Pattern Recognition and Artificial Intelligence (1994), IEICE Transactions on Information & Systems (1994) give a description of the systems and techniques. Several good reviews of the state of the art in this area have been published recently [16, 61, 63].

14 Ways of East–West collaboration in Europe

Now it is time to try to join efforts of scientists from various countries to develop the high quality systems for industry. It is specially true for Europe because to compete with fast developing Asian, American and other companies the developed products must have highest standards and quality. In Europe, there is reserve of forces that is in joining efforts of scientists from Western and Eastern parts that could bring new ideas, systems and results. That is why here we try to consider possible ways of collaboration between West and East European countries.

In the 1980s, the USSR Academy of Sciences had agreements with many Academies and societies of many industrialized countries and all collaboration was made through these agreements. Then, in the beginning of 1990s this form of activity became less effective and in some cases disappeared such as it became only Russian activity. For example, new independent republics like Belarus had to start to find their own agreements that is very difficult in a current crisis in the country and general recession in the world. On the other hand, from the beginning of 1990s, the collaboration between West and East European countries took new forms such as new possibilities were appeared. Let us shortly consider the existing types of collaborations between West and East:

1. Agreements between Academies and other state structures funded from countries budget. This is mainly intended and used for bilateral visits. It continues to work and for new states, new agreements are signed although this process is very slow due to lack of financial resources from both sides. There appeared new types of agreements, not only between Academies. For example, Belarussian Fund of Fundamental Research signed agreements with several countries to fund joint bilateral projects. Ministry of Education has its own agreements with corresponding Ministries on several other countries.

2. Bilateral agreements between research organizations that are usually not funded directly but support researchers of their home Institutes and support, sometimes partially, visit to each others. These agreements are usually useful if any application is submitted for financing of projects or fellowships. An example is an agreement between Institute of Engineering Cybernetics and Institute of Cybernetics of CNR (Napoli, Italy) for collaboration in Image Analysis effective from 1989 that was resigned in 1996 for the next 3–year period.

3. Projects funded from the Western side. It is usually projects that are submitted to Western Foundations and are performed by western scientists with participation of eastern scientists (not Eastern organizations). The example could be projects funded by German DFG Foundation.

4. Individual grants and fellowships that Eastern scientists receive from various Western foundations. It is mainly intended to support individuals. There are NATO, USA National Research Council grants. Many European countries with their Ministries of Education extract money for such grants.

5. Funded projects from the European Commission. There appeared special programs from 1994 where East European countries could participate: TEMPUS, TACIS, INTAS, COPERNICUS, PHARE and some others. East European researchers could also participate without funding in many other Programs but it is not know for me examples of such participation in Belarus.

This is for collaboration between scientists. There is collaboration in applied science, i.e. links between private companies developing mainly software. There are various ways of doing it like establishing joint ventures, making software for western orders, etc. We shall not describe it here.

Among the other new possibilities are joining to various International associations existed in the world. It usually takes money for membership in this Societies but generally it could be solved in each concrete case. Examples are Belarussian IEE Center, Belarussian society of International Association for Pattern Recognition (IAPR) that successfully operate on a base of the Institute of Engineering Cybernetics and others. It allows to have updated information and participate in various events organized by these societies.

Institute of Engineering Cybernetics actively participates in practically all above mentioned points. We have bilateral agreements with many European Institutions. Joint papers are published with colleagues from all industrialized countries. More than 50 researchers of the IEC every year visit foreign Institutes and about 100 foreign researchers visit the IEC. There started to be organized international conferences and workshops in Belarus.

It should be specially mentioned participation of east European organizations in European research programs. Starting from 1994, east European organizations began to participate in some European programs. University scientists participate in TEMPUS, TACIS programs and Academy scientists participate in INTAS and COPERNICUS programs. There are numerous laboratories in IEC that have INTAS projects and some laboratories have COPERNICUS projects.

All considered above says that there are possibilities to join efforts from Western and Eastern parts of Europe to create new competitive products.

15 Conclusion

In this brochure, we considered German and Russian approaches to line–drawing interpretation problem. A comparison has been made between manual and automatic line–drawing input, and between vector and raster types of information representation. To develop automatic input systems, document specifics were analyzed. A general methodology and requirements of document interpretation process was considered. We considered the basic technology stages and show how an initial image is transformed to a final representation. An intermediate image models were classified and described. Possible output image representations for maps and engineering drawings were considered. An overview of the existing Russian and German research systems and approaches was given as well as commercial systems existed at Russian market were considered.

Summarizing, we can say that this area is very important for both countries and they pay much attention to it. The systems developed in Germany, Russia and other East European countries are quite similar although there are some differences too. We hope that this brochure will be useful for all community working in document recognition area.

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