**MVA'90** IAPR Workshop on Machine Vision Applications Nov. 28-30,1990, Tokyo

# Interpretation of Mechanical Engineering Drawings for Paper–CAD Conversion

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**Abstract**

This paper presents an interpretation system for mechanical engineering drawings. After vectorization, all closed minimal blocks with thick lines are extracted. These blocks are analyzed with an expert system to identify higher-level technological entities, which can be transmitted as such to the CAD system.

## 1 Introduction

The extending use of CAD systems leads to the problem, for many companies, of converting existing paper drawings to the internal format of the system. Commercial systems are available but they are mostly limited to *vectorizing* the document, i.e. converting the binary image into a set of vectors. Most of these systems recognize circles, circular arcs, dotted lines etc. The most elaborated have also limited symbol recognition capabilities. However, it would be very useful to recognize in the drawing the basic entities of engineering drawings, such as crosshatching patterns, axis lines etc., and also higher-level technical objects: screws, ball bearings, clips, gaskets, complete shafts, etc. Indeed, these objects, although represented by a large set of vectors, are handled as single entities in elaborated CAD systems and correspond to the company's stock of available parts.

We have implemented a document analysis system for mechanical engineering drawings, which allows a scanned drawing to be input to the CAD system CATIA from Dassault Systemes. In order for the system to be really useful, we have stressed the recognition of these higher-level entities, by matching a set of configurations stored in a library of objects with the drawing being processed. The interpretation is performed by an expert system working on a description of the drawing in terms of *blocks*, the basic entities of our "universe".

To limit the scope of the expertise, we decided to only work on mechanical engineering drawings containing subsets such as gearboxes, reduction gears, pumps, etc. It is indeed very important to convert construction plans for such objects to CAD, as they tend to be often edited when a product line is modified.

## 2 Requirements

In order for the paper to CAD conversion to be usable, several requirements must be fulfilled:

**Accuracy:** The converted information must faithfully respect the drawing input to the system. Whereas partial recognition may be sufficient for conversion of e.g. electronics diagrams, in mechanical engineering the slightest error actually increases the operator's work load: if a shaft measures 48.5 mm on paper, it may or may not have to be adjusted to 50 mm, depending on the context. If the right choice was not made by the recognition system, the operator will have to manually modify all entities placed on the shaft, which were altered because of that choice (ball bearings, gears...).

**Recognition of complex entities:** We must be able to identify the elements which are directly used by a modern CAD system: ball bearings, screws, clips, gaskets, etc. We wanted our method to be more powerful than simple template or pattern matching between the elements of a library and parts of the vectorized drawing.

**Use of all available features:** In order to achieve high-level interpretation, we have to take into account all intermediate-level features which can be extracted from the drawing: specific lines such as crosshatching, dotted lines or axis lines, but also higher-level information such as dimensions [1].

## 3 Extraction of the Basic Entities

To perform interpretation of the digitized drawing, our basic idea is to analyze it using an expert system, with a set of rules relevant to the usual standards in mechanical engineering drawings. The expert system tries out different hypotheses deduced from the features found in various parts of the drawing. However, this analysis does not apply directly to the binary image; the latter is first of all vectorized, and a set of basic features is extracted. The expert system then uses these features as its "building blocks".

The interpretation process has four phases, which will be described in the following sections:

1. a simple and robust vectorization, to convert the drawing into a vector representation;
2. extraction from this structure of axis lines, which always denote a symmetry, and splitting up of the drawing into basic closed curves drawn with thick lines, called the *blocks*;
3. an expert system working with these blocks as "structuring elements" and recognizing entities such as axis lines, shafts, ball bearings, gaskets, screws, housings;
4. the vectors which in this way have been assembled into parts having semantical labels are replaced by the

corresponding element from the CAD library; the remaining lines are corrected by taking the context into account, and the whole drawing is converted to the internal format of the CAD system used.

### 3.1 Vectorization

Many methods have been proposed for vectorizing a technical document, i.e. converting its binary image into a set of vectors [6,3,7]. In this study, we chose a method proposed by Lin, Shimotsuji, Minoh and Sakai [5], originally developed for analysis of electronics diagrams. This method consists in splitting up the image into *meshes* in order to get a broader view of the lines present in the image.

The basic idea in this method is to only look at the intersection of the binary images with the borders of square meshes, whose size is carefully chosen from *a priori* information about the content of the document. The choice of this size should guarantee that only one line at most crosses each mesh border, and that no line is thicker than a mesh. Each mesh is then coded according to the black–white configuration of each of its four borders. Vectorization thus basically consists in following the lines from mesh to mesh.

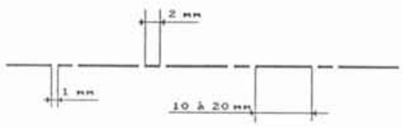
However, although the mesh size is chosen carefully, with help of both semi-automated and interactive tools, there are cases in mechanical engineering where more than one line crosses a mesh, leading to an unknown configuration. We therefore improved the referenced method by using a recursive decomposition of the meshes having unknown configurations, and by recentering the meshes so that no line rides on top of the common border of two adjacent meshes [8].

We also perform some cleanup of the image by eliminating small "barbs" and isolated lines with no connection to the other parts of the drawing. Black areas, for their part, are recognized as such in the mesh following phase and are represented by a coding of their contour. Corner and junction points are also localized; they are the starting points of the subsequent polygonal approximation, which transforms the coding of small segments in each mesh to a set of larger vectors.

### 3.2 Axis Lines and Blocks

Axis lines are represented by successive alignments of alternatively long and short segments, all of them being thin lines. It is very important for the interpretation phase to identify them, as they indicate symmetries. The expert system starts its analysis by scanning all symmetry lines when it tries to identify technical entities, such as shafts and screws, which are located along axis lines.

As axis lines follow a strict representation standard, we just apply this standard to find them:



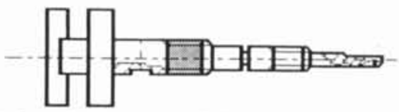

The next step leads to the representation of the drawing as a set of entities on which reasoning can be performed by the expert system: a mechanical engineering drawing is made of lines which represent the contours of objects or of parts of objects. These lines are always *thick*, whereas thin lines only represent the *context* of the objects. Working only on thick lines first, we therefore extract all minimal closed curves, which are called *blocks*. This extraction uses a classical algorithm for finding all minimal closed loops in a graph. Afterwards, the thin lines are associated to the corresponding block, which can thus be given a context: empty (i.e. white), crosshatched, threaded, etc.

## 4 Reasoning on Blocks

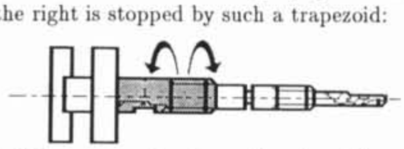
At this state of the interpretation process, the drawing has been divided into a set of blocks whose relative position to one another has a technological meaning: one block of a given type may require a specific type of block as its neighbor. We have represented these constraints as a set of rules in the multi-agent blackboard-based expert system shell ATOME [4], in order to predict the existence and the shape of a block as a function of the blocks already identified.

The search for technological entities proceeds by following the axis lines. The blocks' "texture", i.e. their thin-lined attributes, identify some of them as certainly representing material: threaded and crosshatched blocks cannot represent a hole. These blocks are used as starting points for the reasoning, which determines their neighbors' nature, by applying simple and reliable rules for propagating material along the axis line, i.e. along the shaft being analyzed. Technical constraints relevant to shafts, such as guidings and lockings, are represented by rules in the expert system, allowing for the progressive extension of the interpretation process.

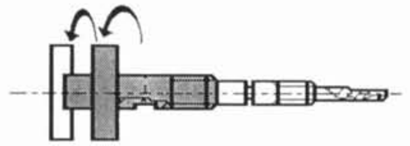
Let us illustrate with the following shaft. A threaded block has been located on an axis line; as such a block *must* represent material, it is selected as starting point:



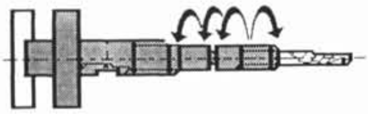
Material can be propagated from an identified block to its neighbors if they have white "texture" and a known geometric shape (rectangle, trapezoid or triangle), or if they are threaded or represent a partial section. Propagation is stopped when the neighbor block has no identifiable geometric shape or if it is a "closing" trapezoid, i.e. one that reduces the shaft's diameter. Here, propagation of material towards the right is stopped by such a trapezoid:



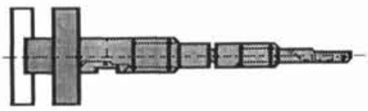
To the left, propagation is continued until we come to a block with undefined geometric shape. As this block encloses its right neighbor (which represents material), it is determined to represent empty space:



If there are still unrecognized blocks, the process is continued with a new starting point, if any is found. Here we start with the threading; the shaft is completely recognized to the left but propagation is stopped by a closing trapezoid to the right:



A third starting point is chosen and leads to identification of the last block:



As the set of recognized blocks contains at least one partial section, we are sure that we have a shaft and not a screw. Relations are then set up between all the component blocks of this entity, which is labeled in the data structure as a *shaft*.

The extension of the analysis of the blocks located on a shaft is based on the fact that there is a well-known set of mechanical devices mounted on shafts: ball bearings, nuts, braces, bearing races, gear wheels, etc. In this part of the work, we especially looked for the components of a locking along the shaft, then for gear wheels which transmit motion from one shaft to another [9]. There are of course many other cases which ought to be studied.

## 5 Correction and Conversion to CAD

We chose not to perform any geometric correction during low level processing. For instance, we don't try to de-skew nearly horizontal or vertical lines. As we saw, the technological rules, for their part, apply to known geometric shapes, with a given tolerance. However, *after* the interpretation of a set of blocks as being a known technical entity, the component blocks can be corrected in order to match exactly the corresponding entity in the library.

The last step consists in transferring the interpretation of the drawing to the CAD system, with the recognized entities being coded as symbols taken from the system's library, and the rest of the lines and blocks being represented in the CAD's standard convention.

As most CAD systems represent a drawing as the superposition of several *layers*, we chose to represent separately these layers in the output of our system. In the CATIA system we used, the recognized layers are axis lines, crosshatched contours, the entities recognized by the expert system, the remainder of the lines — which are further divided into thin and thick lines and long and short lines —, and text or symbols, i.e. small components not connected to the other parts of the drawing.

Figure 1 shows two screen dumps from our system; first a digitized drawing of a reduction gear and second the result of the interpretation. The housing has been located, as well as the hollow parts inside it. Several technical entities have also been identified and replaced with the corresponding elements of the library: ball bearings, screws, clips, pins, gear wheels and shafts.

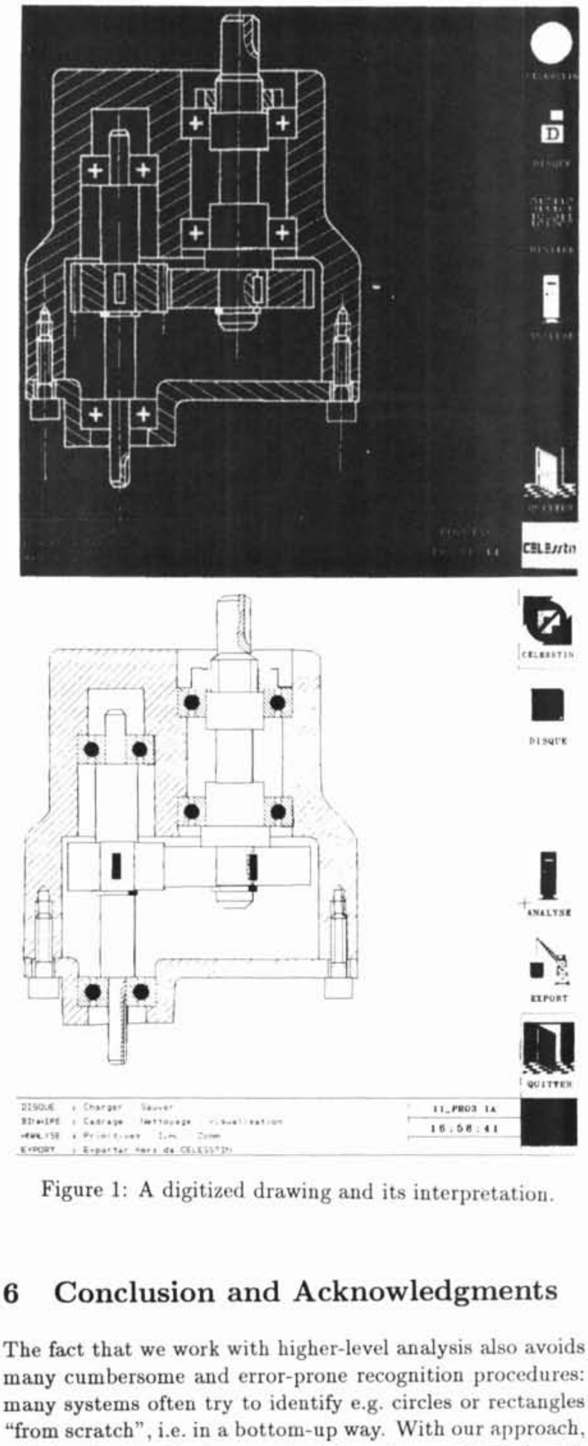


Figure 1: A digitized drawing and its interpretation.

## 6 Conclusion and Acknowledgments

The fact that we work with higher-level analysis also avoids many cumbersome and error-prone recognition procedures: many systems often try to identify e.g. circles or rectangles "from scratch", i.e. in a bottom-up way. With our approach, a higher-level entity is recognized by using mechanical engineering knowledge; the basic geometric components of this entity, such as circles or rectangles, are only inferred after the recognition, and checked on the drawing. Even if the image was deformed, this check will reconstruct the right shape within a given tolerance; conversely, we don't try to force a figure into being a circle, a rectangle or another shape prior to higher-level interpretation.

Our system can of course be extended in several ways. One research direction is to take into account the dimensioning information and more generally all the text written on the drawing, to improve the accuracy of the analysis and to get more information about the nature of the objects and their geometric features. Another topic would be to analyze several views of the same objects in order to get a better understanding of the mechanical device [2]. Of course, the knowledge base we designed for the interpretation process can also be extended a lot, to take into account other devices, other constraints and other areas of mechanical engineering.

The development was partially financed by a grant to ESSTIN, an engineering school, from IBM France. We are grateful to all the ESSTIN students who worked on this project in the last three years, as a part of their computer science course. Thanks also to the ATOME development group from CRIN/INRIA for giving us access to their system.

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