Drawing processing -- Toward facilitating the reuse of old engineering paper drawings in new CAD/CAM systems

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Abstract

Drawing processing has been researched but far beyond satisfaction for many years. An orientational objective is set in this paper as facilitating the reuse of old paper drawings in new **CAD/CAM** systems, and several ways to achieve it are also presented, in which primitive recognition and 2-D drawing understanding are still main problems.

Keywords

Engineering drawing, engineering drawing understanding, vectorization

1 INTRODUCTION

The reuse of existing drawings is very common in the engineering. They may be either consulted in maintenance or modified for new designs. There are a vast amount of paper drawings having been accumulated by now. The amount of paper drawings in service is still growing so rapidly that the storage and the management of them has become a real problem. The introduction of CAD technology has brought forth a reform in the engineering as well as a new problem--how to make use of the old paper drawings in the new CAD systems.

The two problems have initiated the research on the technology of engineering drawing processing, which includes several aspects such as automated paper drawing input,

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vectorization(line detection) and engineering drawing understanding. It is a new research subject that needs the powerful backing of great progresses in the high-tech field.

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2 SIGNIFICANCE AND SITUATION

In order to make use of old paper drawings by means of CAD/CAM techniques, the paper drawing must be inputted into computer systems at first. This procedure can be performed in two ways--interactive or automatic. The interactive way is to draw the drawings manually once again but in the 2-D interactive drawing systems, such as **AutoCAD**, therefore is something like to make new designs in the CAD systems and will not be discussed in this paper. The automatic way of paper drawing input is to scan the paper drawings through scanners. The techniques in scanning and binary processing of image have been improved very much in recent years. Now the paper drawings can be easily scanned into and stored in the computer systems. But the efficient redesign of them remains unsolved.

The redesign on paper drawings through CAD/CAM systems can be operated at three levels, as we understand, raster level, vector level and 3-D model level.

The developments of the high-volume secondary storage technology and the image compression technology have made it possible to store the drawings in computer systems in the raster form in which the drawings usually consumed large spaces before. The modification on the drawings can be performed in a raster image editing system in spite of its low efficiency. The **THDAIMS** system(Li,1993) published by our unit is of this kind. In this system, the drawings are stored and managed as compressed raster data after scanned. A raster image editing system is developed to implement the editing operations such as *erasing*, *moving* and *copying*, as well as the drawing operations. Redesigns over the drawings are performed in this form. This system is serving many users, and meets their demands in some extents.

Not only do vector drawings take fewer spaces than raster ones, but also are convenient to be modified. In vector drawings, the binary bits from raster ones have been grouped into vector data, therefore can be picked and edited efficiently as meaningful groups--vectorial primitives. A paper drawing is stored in the raster form after scanned. It needs a so-called-vectorization processing to convert the raster form to the vector form. After vectorization, the drawing can be edited through a 2-D interactive drawing system, such as **AutoCAD**. But the vectorization is often error prone due to the noise in the raster image of the paper drawings, and the employed method of thinning and tracking usually results in distorted vector primitives. The errors and distortions in vector drawings require so much correction that the efficiency of modification at vector level is offset. Although many commercial products, such as **THRV** (Liu, 1993) published by our group, have already been developed, the performance of vectorization needs much more improvements. Many researchers are still working toward this target.

While the research on vectorization was being undertaken, another research work was placed on the agendas of researchers. It is engineering drawing understanding. It has several levels of processing, as Dov Dori mentioned in one of his paper(Dori, 1993), from the lexical level to the semantic level. Its final objective is 3-D reconstruction of objects through 2-D planar drawings. It is a critical procedure to complete the 3-D reuse of old paper drawings. The conversion from 2-D drawings to 3-D models not only facilitates making new designs over old ones but also makes it possible to use old drawings in 3-D CAM systems.

For more than a decade, researchers have not found a better way to achieve the target. In early years, researchers tried to construct the object model only through its orthographical projections(Haralick, 1982) but failed because the solution is not exclusive. This problem is attracting more and more researchers' attentions these years. The understanding process is divided into several procedures, among which the dimension understanding of 2-D drawings has been well researched(Dori, 1988, 1989 and Min, 1993) and therefore provides a strong support for further understanding of drawings. Knowledge-based understanding is also employed to get a better understanding of special components in the drawings(Vaxiviere, 1992). But the main problem of 3-D reconstruction remains unsolved. This problem is so difficult that many researchers shrink back before it.

Therefore, the state of art is: although drawing scanning and drawing processing at raster level are better solved, the efficiency of raster level modification can not be accepted by users in most cases; the performance of vectorization is so far beyond the users' satisfaction that users can not undergo so much vector level modifications; and the 3-D reconstruction is so difficult to implement that the 3-D redesign is just a dream. The researchers are now in such an awkward predicament

Currently, There are still strong desires from the engineering field for making use of the old paper drawings accumulated over a long period of time in the new CAD/CAM systems. Therefore the reuse techniques of paper drawings, that is, effective and efficient processing of engineering paper drawings must be solved as soon as possible.

3 WAYS OUT

As we mentioned above, improving the performance of vectorization and undertaking understanding of engineering drawings are still many researchers' objectives. But their research subjects are limited to it unfortunately. There is little progress having been made in this field for many years because of its high complicacy. Here we suggest that new subjects in this field should be created, selected and researched to extricate us from the predicament.

(1) Facilitate the 2-D interactive redesign.

The commonly used methods are only but unfortunately either interactive or automatic to perform the modifications over those drawings that exist in computer systems. Why not try to use them simultaneously? The raster level editing is always considered as an interactive or non-automatic operation, while the vectorization processing is usually thought to be an automatic or non-interactive process. To combine the two methods, there may be several ways to improve the efficiency of interactive modification of drawings, as presented hereinafter:

Perform local vectoriaztion interactively in the raster level editing system.

Among the three levels of reuse of paper drawings, as we mentioned above, the raster level is easiest to achieve in spite that the manipulations at this level are always boring. So the way to solve this problem is making it easy to perform the operation at this level. But how can we change this situation? We must go beyond the traditional ways of performing raster operations such as *erasing, moving, copying and drawing with paintbrush.* The new method suggested here includes two aspects: vectorizing interactively and drawing on raster background. The techniques of locally automated vectorization should be used to perform interactive selection of groups of bits. That is, to carry out automatic vectorization on those raster pixels which are stretched to from a selected point or within a local area that is given by the user interactively. In this way, the user can pick those meaningful groups of bits not in regular areas, such as lines and arcs, therefore the editing operations of them can be performed efficiently. And drawing vectorial graphical primitives on a raster background can help user to position quickly, therefore can speed up the 2-D interactive drawing process. The vectorial graphical primitives can be saved onto the raster background. Imposing these two aspects of improvements into the raster editing system can facilitate the modifications on raster drawings.

Perform primitive recognition interactively in the vector editing system.

Now that the situation is that the bars are always too fragmentary to represent meaningful primitives after vectorization, and they are inconvenient to be picked and modified as primitives, effective and efficient ways to group them to meaningful primitives should be found and used to facilitate the modifications. The way suggested here is that adding interactive primitive recognition functions into the 2-D vector editing system. A group of scattered bars should be selected and transformed to meaningful primitives by user interactively, such as longer straight line segments with different line styles. For example, In the following piece of drawing, the parts(1, 2, 3 and 4) of the central line are scattered and one part(the dot between part 1 and 2) is discarded in vectorization, it will be easier to recognize it interactively by means of giving the clue of its two end points or its all parts than it will be to recognize it automatically Perhaps circular arcs are the most difficult primitives to be extracted in the procedure of vectorization. But the interactive way to find them is very easy because centers and radiuses of these circular arcs or circles given interactively by users are always more precise than those ones that are automatically fitted.

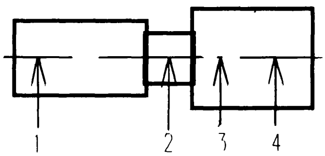

Figure 1 A sample of interactive primitive recognition.

Although it is interactive, this method is different from re-drawing the paper drawing once again. First of all, the interactive recognition is based on the results of automatic recognition which inevitably have some errors in them. Secondly, these interactive operations can be accepted by users because of their small amount.

(2) Endeavor to 2-D understanding of engineering drawings and its applications.

Now that the path toward 3-D understanding is out of our current sights, why not just do our best in 2-D understanding? In fact, 2-D understanding is easier than 3-D understanding and has some promising applications. Some researchers have done some parts such as dimension understanding and 2-D component/block recognition. These fruitful basic works make it possible to do 2-D semantic understanding. Actually, as the basis of 3-D understanding, the research on 2-D understanding will help to approach this final goal.

Similarly, the automatic 2-D understanding can also be helped by means of users' interactions. While the detail of 2-D understanding will be discussed in section 4, here we propose two new applications of 2-D engineering drawing understanding which will enrich the research work in this filed.

Perform 2-D parameterized redesign after 2-D understanding.

A semantic description of the 2-D object will be obtained after 2-D understanding, therefore constrained relations among the dimensions of all its parts can be calculated. The constrained relations make it possible to redesign by modifying the dimensions. This is a higher level reuse of old paper drawings and will improve the utility of old paper drawings in 2-D CAD systems effectively

Turn to 2-D CAM.

Some engineering drawings are descriptions of flaky objects and for 2-D manufacturing. After 2-D understanding of these drawings which is not so difficult as 3-D understanding, the 2-D objects' shapes are recognized. 2-D manufacturing instructions can be calculated according to the automatically recognized 2-D shape. Then 2-D CAM can be realized.

These two proposed applications will change the current situation in this field. It is an attracting idea to set up an automatic workshop which can complete every operations from drawing input to 2-D dimension-driven redesign and 2-D CAM. But how can we make it true? Automatic 2-D engineering drawing understanding is a critical problem and should be solved first To solve it, here also we propose a route on which automatic 2-D understanding is not too far to be reached but also needs large amount of research work under the current conditions.

4. TOWARD AUTOMATIC 2-D ENGINEERING DRAWING UNDERSTANDING--A PROPOSAL

4.1 What Is Understanding?

To perform engineering drawing understanding, we should first understand what its meaning is. What kind of results should be obtained to show the computer has understood the drawings.

No standard has been set yet. How can we do it if we do not know what it needs to do? In this section, we will first try to give it a lowest standard and then work toward it.

An engineering drawing is created by one man for other men to understand what object it describes. How does a trained person understand it? After some kind of analyses, the exact object will be constructed in his/her mind finally. But how does a computer understand the drawing? If the 3-D model of the object is constructed and displayed, we surely can say the drawing is understood by the computer. Maybe this is the highest standard and the final stage work of engineering drawing understanding. There are several stages of pre-work before the 3-D model of the object is constructed.

The binary image should be vectorized first. Graphical primitives should be recognized then. These processings are very easy for men, even the untrained men. They can recognize these primitives even with the first look. Therefore these processings can not be called understanding. Dimension recognition is a further processing of these primitives. Special syntactic and semantic analyses should be applied to do it. But it just adds dimension attributes to these primitives, and therefore it can not be .called understanding either. What can be called understanding, then? We believe that at least the functions of vectorial graphical primitives and the logical relations among them should be known if we say the drawings have been understood For example, It should be clear which lines are representing for contours, what relations (connecting to, containing, or of other kinds) they are among these contour lines, and which contour lines are making up parts of the object. After these information has been obtained, dimension attributes can be attached to them to get their shapes, even 3-D shapes from only one projection This is the lowest level of understanding of engineering drawings, as we understand. It is still a 2-D processing. We just call it 2-D understanding. Although there are steps before 3-D reconstruction, It is enough for 2-D dimension-driven redesign and 2-D CAM. We should fight for this goal first.

4.2 How to Achieve It?

In the current situation, the performance of vectorization and primitive recognition is still perplexing us. The difficulty of improving it is still very high because the vectorial parts of primitives are always inexactly extracted out and usually intervened with others. Although interactive ways can be optional, automatic ways are still preferred. Therefore researchers should endeavor to it. Moreover researchers should expect that the problem of 2-D engineering drawing understanding be solved on the basis of good performance of vectorization and primitive recognition.

In Figure 2, we propose a route of performing 2-D engineering drawing understanding, as well as related works. On this route, the text/graphics separation module is always at the beginning point. The new idea suggested hear is adding a module of primitive recognition after vectorization as well as imposing iteration into primitive recognition. The task of vectorization module is reduced as just extracting the short bars(straight line segments) which will precisely simulate the original drawings after thinning and tracking. The primitive recognition module is expected to extracted the meaningful primitives such as circular arcs, contour lines, hatching lines, central lines, dash lines, arrow heads, etc. Iteration is also suggested to be embedded into character recognition while the text patterns are being recognized. Recognized dimensioned primitives are also helpful for the detection of errors and unrecognized primitives(both graphic primitives and text primitives). 2-D understanding then can be performed on the basis of the

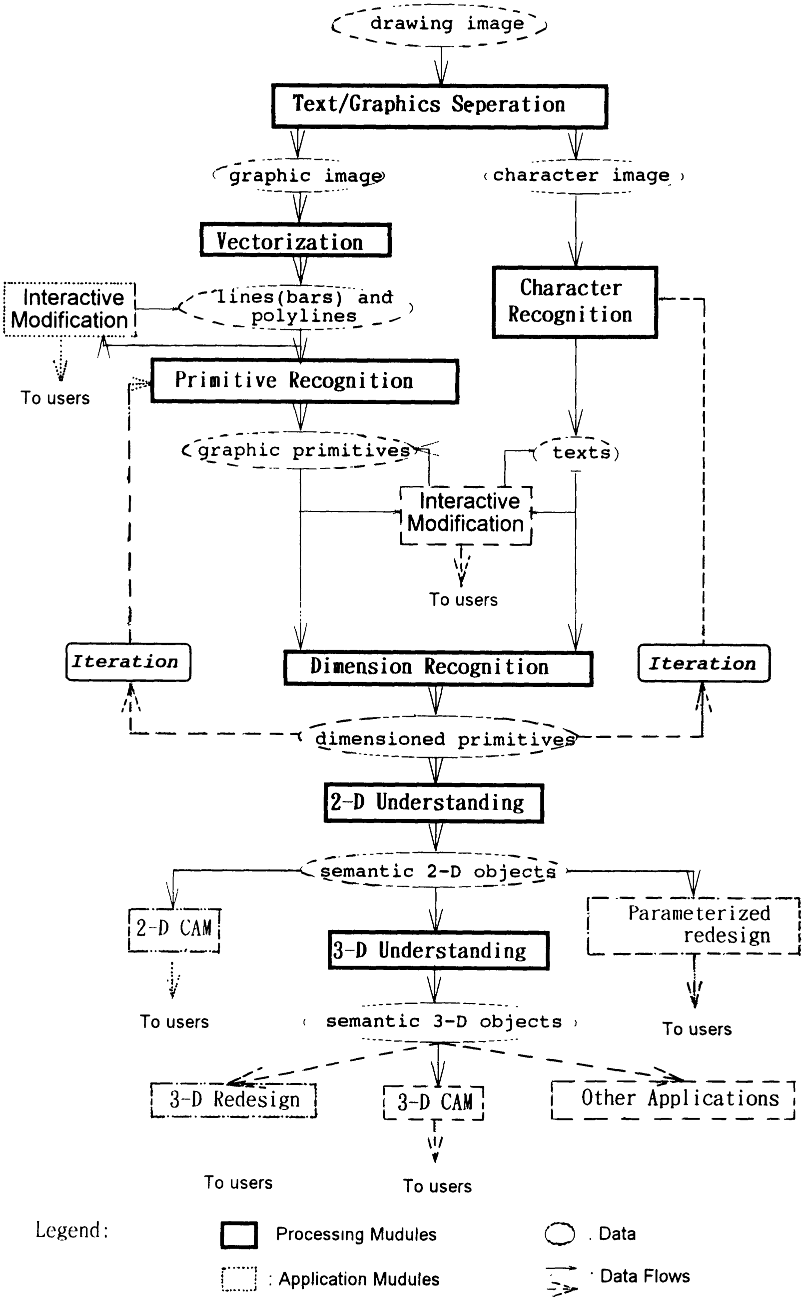

Figure 2 Engineering drawing processing procedures and their applications

well recognized primitives. In the figure, we also propose some practical applications based on different stages of achievements that will satisfy the users at different levels.

As a low level procedure, vectorization should not be expected too much. Fragmentary bars are enough results from it. And this procedure is enough for practical use for the processing of those drawings on which there are only free curves, such as contour maps. Primitive recognition should be performed as its post-processing procedure on the basis of its results if there are high level vectorial primitives in the drawings. In the primitive recognition procedure, domain knowledge should be employed to guide the recognition of primitives. For example, dimension set patterns in the engineering mechanical drawings are always different from those ones in engineering architectural drawings, therefore the recognition processes of them should be different. The drawings of contour lines, hatching lines, central lines, dash-dot lines, and arrow heads are under more strict rules in engineering mechanical drawings than in other drawings. Even the engineering mechanical drawings have some different types. The assembling drawings consist of more complex primitives than other kinds of mechanical drawings.

In the primitive recognition, the iteration of recognition is as important as the knowledge-based method, because the rules must be applied to the data which are generated from the recognition process and its pre-process. And In the iteration, the non-monotonous reasoning method can also be applied to it to get the most possible results when there are so few evidential data that the recognition process can not continue.

As a higher level procedure of drawing processing, 2-D understanding can be carried out on the basis of the recognized primitives. To perform this procedure, It is necessary to make some basic definition of syntactic and semantic rules that guide the description of 2-D objects/blocks. But unfortunately, only can the formalized description of the grammar of dimensions in mechanical drawings be found in the literary. The understanding process of 2-D engineering drawings is the process that detects the rules of 2-D object description and obtains the semantics in that description.

5 MAIN PRESENT PROBLEMS

As mentioned above, The main problems perplexing us currently are still the methods of primitive recognition and 2-D understanding. As long as they are not solved well, the efficient and effective reuse of paper drawings and automatic 3-D understanding can not be carried out and other following procedures can not be realized.

In primitive recognition, the syntactic and semantic descriptions of primitive constructions should be formalized as that of the dimension sets have been done. Perhaps the grammars of these primitives are not so complex than that of the dimension sets. But it is not so easy to implement them on the real data in the practical systems On the contrast, there is no syntactic or semantic descriptions of 2-D objects/blocks, even less the realizing method to serve the understanding of 2-D objects/blocks.

Because of its high complexity, we suggest that the knowledge-based method rather than the traditional method of pattern recognition should be used to achieve the goal. For completing the automatic primitive recognition and 2-D drawing understanding, here we list some primary problems that should be solved first.

- knowledge representations of primitive descriptions;
- iterative reasoning(non-monotonous reasoning in particular) on them;
- acquisition and representation of syntactic and semantic descriptions of 2-D objects/blocks.

Moreover, it is not too early to list the problems of 2-D CAM and 2-D parameterized design on the researchers' agendas.

6 CONCLUSION

In the current conditions of research works, the reuse of engineering drawing at vector level is still the most preferable choice. Therefore improving the performance of vectorization and primitive recognition is still our main objectives. But it is very utilitarian to make use of current capability in applications For examples, as shown in Figure 2, after the procedures of vectorization, lines and polygonal lines are enough for some users, while other users are satisfied with (dimensioned) primitives which result from the procedure of primitive recognition or dimension recognition.

But for higher level of applications, 2-D engineering drawing understanding is still taking a critical role. It is at once the basis of 3-D understanding and the sole way to 2-D CAM and 2-D parameterized redesign, therefore deserves more attentions.

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