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A SYSTEM FOR AUTOMATIC DRAFTING ENCODING

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ABSTRACT

A complete software system for automatic drafting encoding is described. This system decomposes the original draft into a graphic primitive-based description,suitable for subsequent CAD processing. Problems relative to the binarization phase and the symbol recognition step are also covered and a hybrid approach is proposed.

INTRODUCTION

Computer Aided Design and Drafting procedures are spreading out, mainly due to the compact, non-redundant and easy to modify representation, that can be obtained through these techniques.

Technical drafting is not only an important but also a powerful communication and planning tool in many disciplines; this is why a vast number of drawings exists ranging from civil and electronic applications to cartographic and business graphics. All these documents have two main common features: the high rate of modification they undergo and their long lifetime (generally of tens of years).

Moreover there are, at present, many well-established manipulation techniques, based on computer systems, that allow drawing processing.By using such techniques it is now possible to introduce the concept of "work reusability" in the drawing domain. Through CAD methodologies, it is possible to build an efficient data base of technical drawings, in order to recover, modify and adapt previous jobs to new situations and projects.

This is a very attractive approach since previous projects can be recovered and suitably adapted to new projects with a substantial time saving.

One of the most important bottlenecks is the fact that the major part of today's documentation is not in a form suitable for CAD processing. In the past, a lot of standard graphic devices such as light pens, tablets, mice, joysticks, etc... were adopted to convert traditional drawings into a CAD compatible format. Many semiautomatic software packages were designed to help the operator in point positioning and curve tracking tasks. Nevertheless, this kind of software for data input produced time-consuming, expensive, tedious and error-prone procedures, especially when large drawings were involved.

In this paper an efficient method to extract a graphic primitive-based description from a digitalized drawing is described. Such a description is suitable for use with a CAD system, since the whole drawing is decomposed into arcs and segments, while the embedded text is processed separately.

THE PROCESSING CHAIN

Converting a draft into a CAD compatible format is a multistep procedure that involves: digitalization, sensor response correction, thresholding, symbols identification and coding, drawing line encoding.

First, the original drawing must be digitalized by using a system capable of a 0.004" resolution referring to a 34×44" document; this resolution allows the grabbing of all the significative lines and symbols belonging to the document itself. There are systems using flying spot scanners or friction drums or movable beds under fixed CCD arrays or movable CCD arrays on fixed bed that can be successfully employed in this initial conversion; in our experiments, a CCD based scanner was used with a moving head and a fixed document bed capable to acquire drafts up to A0 format.

In order to obtain good results from the digitalization step, an array response equalization is performed by using some predetermined factors obtained during an initial learning step. In this phase, a certain number of white lines corresponding to the typical document background is acquired and for each elementary sensor the following value is computed:

$$A_1 = (MX*N)/(R_{i1}+ R_{i2}+...+ R_{iN})$$

where N is the number of background lines acquired, while R_{iL} is the i-th elementary sensor response on the L-th line and MX is the maximum grey level (255 for an 8 bit A/D converter).

During the normal image acquisition, the i-th sensor response is multiplied by A_i;this preprocessing counteracts the 6% response drift from elementstypical of CCD arrays and contributes to the background homogeneity. After the digitalization step, a noise filtering is applied by using a 5×5 mask and evaluating five 3×3 subwindows as shown in Fig. 1.

A	B	C	D	E
F	G	H	I	J
K	L	(M)	B	O
P	Q	R	S	T
U	V	W	X	Y

A	B	C
F	G	H
K	L	(M)

C	D	E
H	I	J
(M)	N	O

G	H	I
L	(M)	N
Q	R	S

K	L	(M)
P	Q	R
U	V	W

(M)	N	O
R	S	T
W	X	Y

Fig. 1 - 5×5 filtering mask and the relative five 3×3 subwindows.

The mean of that subwindow having minimum variance is substituted to the central pixel value.Other methods, such as half-neighbouring [1], were also tried with similar results. After the noise filtering step, a thresholding is applied; some usual algorithms were tested like: the deepest valley between peaks [2], [3], the maximum entropy bipartition level [4] or other methods like Fukinuki's [5], [6]. The linear bidirectional interpolation of local threshold suggested by Rosenfeld [7] was also tested, but the results were not very good in this application, taking into account the computational burden.

Two other new approaches performed well. The first one is based on two scans of the whole image, one horizontal and one vertical; during each scan a moving average window is displaced along each line and the mean values are computed at various positions which convey information about the local luminance drift.

Those pixels, which have a value less than the window mean value at their positions by more than a fixed threshold in both vertical and horizontal scans at the same time, are marked as background points, and the others as drawing points. In this way it is possible to adapt the threshold value to the local illumination implicity, and to obtain a shadow correction effect (Fig. 2).

a)

b)

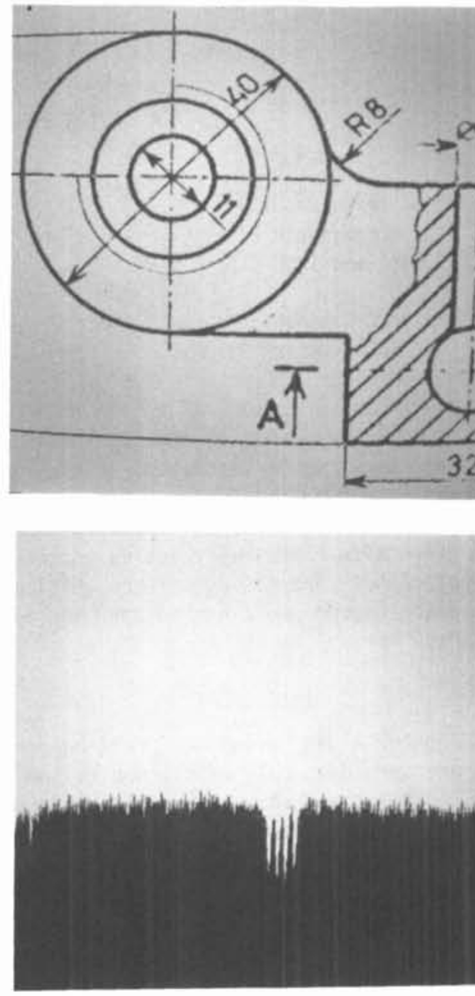

Fig.2 - a) Binarized image. b) Row grey levels with superimposed moving window-average values.

The second method subtracts from the whole image a background estimation; to this end instead of using percentile filtering [8], a new approach is proposed which is based on the subtraction of the original image from a copy shifted by a certain amount in the four main directions. The principle is that the drawing lines, if suitably displaced, will be superimposed to white pixels belonging to the local surrounding background. In this way all the lines can be filled with background pixels in the immediate neighbourhood and a white image without lines is obtained, taking into account local illumination variations. Drawing lines can now be extracted by subtracting from the original frame the previous background estimation.

The whole algorithm operates as follow:

1) four difference images are generated by shifting the original image in the four directions: left, right, up and down, and by subtracting the original from its displaced versions;

2) for each pixel, the corresponding pixels in the difference images are analysed and the values of the shifted image for those exceeding a certain threshold are accumulated. Then, the mean of these values is substituted instead of the original pixel value;

3) if there are no pixels exceeding such a threshold in the difference images, the pixel under analysis is left unchanged.

In the actual implementation the four displaced images need not to be generated because suitable tests on the original pixel values can be used in their place.

This algorithm works very well also in the case of relevant local illumination drifts.

After computing the binary image, the next step is the skeleton extraction. Many thinning techniques are well-suited for this kind of processing [9], [10]; in our case the Arcelli's thinning algorithm [11] based on the Distance Transform was used. The thinned image is obtained by means of a labeling procedure that preserves thickness data, since the original pixels are only suitably marked and not discarded; a further data recovery can then be performed (Fig.3).

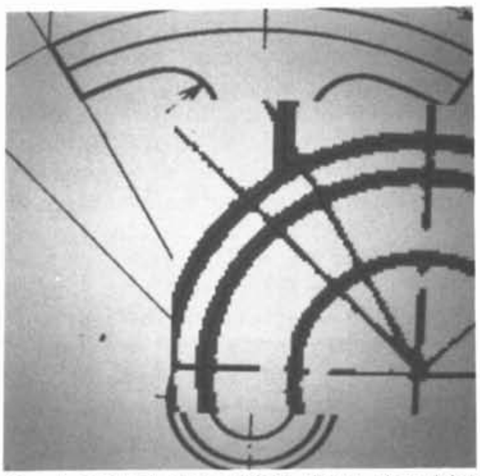

Fig. 3 - A zoomed part which shows the thinned image and the marked pixel.

In order to obtain a better regularity of the line contours and avoid small holes and imperfections, a preliminary non-linear filtering is applied to the binary image.

The algorithm scans the whole drawing and those white pixels (background) having five or more black (drawing) neighbourhood pixels are set to black.

Morphological filtering like Suzuki's fusion [12] is also well suited for this kind of regularization step, but at the expense of a greater computational burden.

Notwithstanding this line regularization, Arcelli's method produces a certain number of little spurious branches, due to residual line imperfections and to noise; thus, a post-processing step (pruning) must be applied to remove them. At the same time, this post-processing produces other useful effects on line straightness, by adding a pixel to those configurations satisfying the following two conditions:

1) the pixel is the starting pixel of a "good branch" (that is to say of a branch that must not be removed);

2) the pixel matches the following configuration mask or one of those obtained by 90° rotations (Fig. 4).

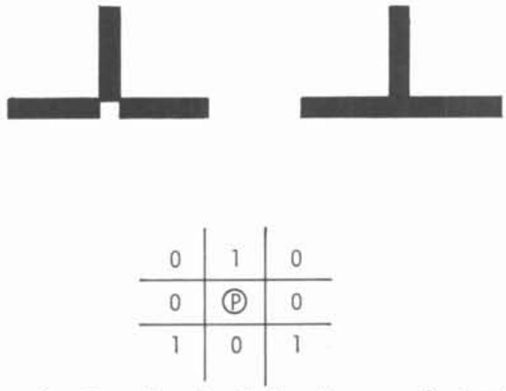

Fig. 4 - Example of a T junction regularization

The pruning algorithm follows each branch from its ending point to the nearest branching or ending point and removes the whole branch if its length is below a certain threshold. If the branch can be preserved, the final point configuration is inspected to see if it matches one of the masks, and then the configuration is completed as shown in Fig. 4.

Next, another processing step is used to fill residual little gaps in the skeleton. Such a processing is a two-phase method: during the first phase special points in the skeleton are identified (branching points, ending points, high curvature points); then, a search is performed starting from the ending points (those with only one neighbouring pixel).

The search aims at identifying a near special point having a leading segment collinear enough to that of the ending point under investigation.

In practice,the algorithm works in the following way:

1) a certain number of pixels belonging to the segments leading to the actual ending point is considered. A best fit segment is evaluated by forcing it to pass through the ending point;

2) then, the search proceeds in a circular sector symmetrically centered around the direction of the best fit segment. The sector radius is a predetermined constant;

3) for all the special points inside this

sector a similar best fit segment is evaluated and that showing the most similar direction, with respect to the search direction, is selected;

4) the ending point and the selected special point are joined with a segment.

The second processing phase is identical to the first one except for the parameter values; in fact, the first phase uses a little sector radius and a relatively large sector angle, while the second phase uses a relatively large sector radius and a relatively small sector angle.

This corresponds to the fact that the little gaps are filled by giving less relevance to directional information; when all these gaps have been filled a second phase is tried in order to fill larger gaps but, in this case, a greater importance is given to the line directions to prevent erroneous connections. In this way, it is possible to reconnect linear characteristics broken into well aligned but highly fragmented regions (Fig. 5).

a)

b)

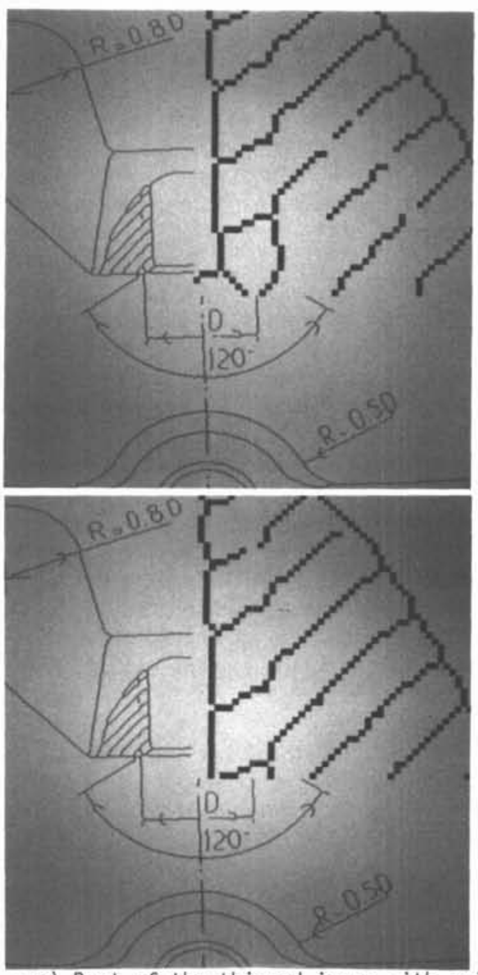

Fig. 5 - a) Part of the thinned image with noise generated gaps. b) Post-processed image with filled gaps.

At the end of this processing chain, a thinned image is obtained whose lines represent the skeletons of the original drawing lines; thus, it is possible to start the drawing decomposition into arcs and segments.

SKELETON INTERPRETATION

Instead of using the usual techniques that start with a segment and try to build a polygonal approximation by merging all those segments with the same direction (according to a certain tolerance range) [13], [14] a different approach based on the analysis of the global structure of the skeleton was used.

Psychological studies demonstrate that the major information contents of a diagram is recoverable by analysing the way in which special points like branching points, ending points and high curvature points are interconnected (i.e. their topology). For this reason, the skeleton was interpreted as a graph whose nodes represent the special point positions and whose branches carry information about drawing topology and line or arc shapes. Then, the whole drawing can be analysed and described by using a lower number of primitive elements because we assume that two linked special points contain a single primitive element.

We also have a stronger confidence during primitive type selection since, instead of having to decide where a primitive starts and where it ends by building up this information from localized analysis; we already have such an information and we can use all the pixels between two special points to identify what kind of primitive we are dealing with.

Once all the primitive elements in the drawing have been selected, thickness data are recovered by taking into account the number of pixels belonging to drawing lines (marked during the thinning phase) and counted in a perpendicular direction with respect to the primitive under examination.

The mean thickness is evaluated by going from the starting to the end point and the resulting value is compared with a table of predetermined standard values which refer to real line thickness. The nearest value is selected and stored along with the corresponding primitive type and position information (Fig. 6).

The special points considered are multiple points, terminal points and high curvature points.

Terminal points are those having a single neighbouring pixel, multiple points have more than two neighbouring pixels and high curvature points correspond to high line bending.

All these points are suitably marked by scannning the graph skeleton structure and are used as a starting point for drawing interpretation.

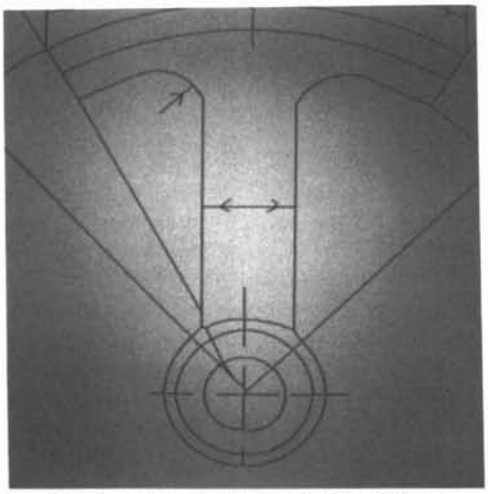

Fig. 6 - Reconstructed image coded with segments and arcs. Text is not shown since it is processed separately. No post-processing has been applied for circle correction.

Due to noise and other shape irregularities,some special points may appear near each other. Those points which are closer one another than a predetermined threshold are clustered and decimated, so that only one survives in a certain region.

A hierarchy is used during the decimation step, by stating that the survivor must be the higher multiplicity point. However high curvature points are never squeezed.

Then symbol identification is performed.The basic concept in locating symbols rests on the fact that they generally enclosed little background regions; so background region areas can be used to identify potential symbols.

The whole skeleton creates a partition of the image background in a set of regions that are those comprised in each closed chain of skeleton branches.

Background region sizes are computed and their values are clustered into two classes: large-sized regions and small regions.

A chain of skeleton branches touching a little background region is considered as pertaining to a potential symbol.

In order to obtain a fast and reliable classification,a new method is proposed which is based both on topological information relative to symbol lines and invariant features concerning the background regions enclosed by the symbol lines and considered as elementary objects.

In particular, segments, arcs, number of corners, linking branches, angles between elementary graphic primitives, etc. are used to extract topological information, while Fu's invariants, compactness, normalized diameter, etc. are employed to obtain a preliminary description of the background regions enclosed in the chain of primitives relative to the potential symbol.

In this way, an initial search is performed in the symbol library by looking for symbols having similar background components and then topological data are used to take the final decision.

This hybrid approach uses at the same time graph-matching and invariant-matching techniques and allows a good symbol detection and classification. After a symbol has been recognized, the corresponding skeleton branches are removed from the image and the whole symbol is represented by using a predetermined code stored in a symbol library.

If symbols are removed before trying a primitive decomposition, a simplification is achieved, since small details are usually difficult to deal with.

In order to identify the best graphic primitive to be used in draft encoding, all skeletal points comprised between a pair of special points are then checked and the graphic primitive (arc or segment)giving the best match is used.

At last, a drawing decomposition into graphic primitives is obtained and line thickness data are store.

TEXT PROCESSING

During the symbol detection step, character strings are also identified because they are relatively small and isolated regions do not touch drawing lines. Each character is isolated by using a suitable box and then recognized through a character recognition algorithm such as Ledeen's algorithm [15]. This algorithm works in the following way: a suitable box is fitted around character strokes and some features are extracted. To this end, the whole rectangular box is divided into nine regions equally sized by using four lines; then the region in which the stroke begins, the number of times it crossed each dividing line and the stroke position relative to other strokes making up the character are extracted.

In order to code relative position data, each stroke making up the character is analysed on the basis of the nine previous regions;then a pseudo stroke is generated by joining the centers of all the regions surrounding the component strokes and then is coded according to a predetermined table (Fig. 7).

Stroke relative positions along with previously evaluated features are compared with a suitably organized dictionary prepared in an initial learning phase and so each character can be recognized.

1 1 0 0	0 1 0 0	0 0 0 0
1 1 0 1	0 1 0 1	0 0 0 1
1 1 1 1	0 1 1 1	0 0 1 1

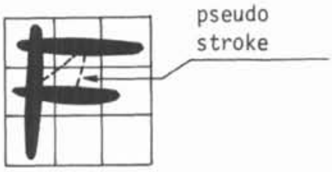

Fig.7 - An F character comprising three strokes and the relative pseudo stroke

In such a way text and numbers can be stored in ASCII code along with positional informations, obtaining so a great compression ratio.

CONCLUSIONS

A system for draft encoding using hybrid procedures, based both on graph and pattern recognition techniques to identify and match special symbols, has been implemented. Thus it has been obtained a great data compression ratio during drawing enconding. The whole system has been coded using C language on a MC68020 based system running under UNIX V AT&T operating system. A linear CCD array mounted on a movable head and able to scan up to A0 format was adopted during the digitalization phase.

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REFERENCES

[1] A.Scher, F.Velasco, A.Rosenfeld, "Some New Image Smoothing Techniques", IEEE Trans. Syst. Man Cybern, May 1980.

[2] A.Rosenfeld, A.C.Kak, "Digital Picture Processing", Academic Press, New York,1982

[3] A.Rosenfeld, P. De La Torre, "Histogram Concavity Analysis As an Aid in the Threshold Selection", IEEE Trans. Sys.Man and Cyber. SMC-13, n.3, April 1983.

[4] J.N.Kapur, P.K.Sahoo, A.Wong, "A New Method for Grey Level Picture Thresholding Using the Entropy of the Histogram", Comp. Vis.Grap. and Image Proc., 29, 1985.

[5] T.Fukinuky, "Notchless Bi-Level Quantizer for Facsimile and its Effect on Coding Efficiency", IEEE Trans. on Common., COM-26, 1987.

[6] S.Weszka, A.Rosenfeld, "Histogram Modification for Threshold Selection", IEEE Trans. Syst. Man and Cyber., SMC-9, n.1, January 1979.

[7] J.S.Weszka, R.Nagel, A.Rosenfeld, "A Threshold Selection Technique", IEEE Trans. on Computer, December 1984.

[8] C.A.Groen, J.van Munster, "Computer Aided Analysis of Schematic Diagrams", Pattern Recognition in Practice II, Elseviers Science Publisher, Amsterdam, June 1985.

[9] T.Pavlidis, "Algorithms for Graphics and Image Processing", Springer-Verlag, Berlin-Heidelberg, 1982.

[10] T.Pavlidis, "Structural Pattern Recognition", Springer-Verlag, Berlin-Heidelberg, 1977.

[11] C.Arcelli, G.S.di Baja, "A Width Independent Fast Thinning Algorithm", IEEE PAMI-7, n.4, July 1985.

[12] S.Suzuki, K.Abe, "New Fusion Operations for Digitalized Binary Images and their Application", IEEE PAMI-6, 1985.

[13] W.Pferd, K.Ramachandran, "Computer Aided Automatic Digitizing of Engineering Drawings", Proc. of Comp.Soft.Appl.Conf., IEEE Chicago, Illinois, November 1978.

[14] K.Ramachandran, "Coding Method for Vector Representation of Engineering Drawings", Proc. of IEEE, vol. 68, n.7, July 1980.

[15] W.Newman, R.Sproull, "Principles of Interactive Computer Graphics", Mc Graw Hill, 1973.