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A CAD BASED KNOWLEDGE VISION SYSTEM FOR 3D OBJECTS RECOGNITION

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ABSTRACT

This paper introduces a layered knowledge based vision system for industrial environments. We focus on model building for 3-D objects using a commercial CAD system and expressed in the vision based representation form. The vision based model involves information extracted from DXF description. The feature information from CAD model is represented as a CAD based frame. On the other hand, in the knowledge-base vision system presented here a method for shape from shading is implemented, which allows a classification or a detailed reconstruction of the surfaces in the scene. As a features defined from an image, we have used edges and contour information, surface orientations, depth, Extended Gaussian Image (EGI) and surface shape information. The basic concept of presented system is to match image features defined from an image and available CAD based features from the same object. This system can be applied for image understanding of two kinds of objects: objects described by smooth convex visible surfaces; objects described by their shape peculiarities (features). The system consists of several modules and is written in Language C. It runs on microcomputer IBM/PC.

INTRODUCTION

Flexibility in planning, designing, assembling and manufacturing products is most relevant to modern industry.

The problem of linking CAD and Vision system is very difficult, and this is the basic purpose for the researchers to begin applying AI techniques [1,2,3,4].

In this paper, we focus on the adaptation of preexisting CAD models of objects for vision recognition system. We have developed a system which used 3D object descriptions created on a commercial CAD system and expressed in the vision based representation form, which is stored in a database of models for object recognition. The vision based model involves information extracted from the IGES (Initial Graphics Exchange Specification) or DXF (Drawing Interchenge File) description.

In the knowledge-base vision system presented here a method for shape from shading is implemented, which allows a classification or a detailed reconstruction of the surfaces in the scene [5]

. As a sensory data, we have used intensity image. As a features defined from an image, we have used edges and contour information, surface orientations, depth, Extended Gaussian Image (EGI) and surface shape information. The system consists of several modules and is written in Language C. It runs on microcomputer IBM/PC.

This system can be applied for image understanding of two kinds of objects:

- objects described by smooth convex visible surfaces;
- objects described by their shape peculiarities (features).

SYSTEM COMPONENTS

A general architecture of a system for image understanding of grey

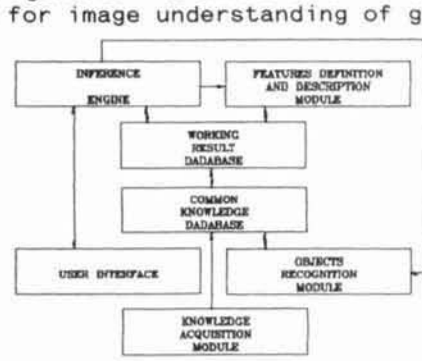

Fig.1

scale images is given in [3]. According to that architecture we present knowledge-based vision system consisting of the following components:Common knowledge database;

Working result database; Knowledge acquisition module; Features definition and description module; Objects recognition module; Inference engine; User interface (Fig.1).

COMMON KNOWLEDGE DATA BASE

The system presented here has a layered knowledge base architecture. The knowledge is stored in three different layeres: the layer of facts; the layer of inference rules; and the layer of metarules. Metarules in the top layer are used to control the actions in the next layer- the layer of inference rules. Inference rules are used for facts analysis in the bottom layer and for achieving the goal-generating operation plans. The knowledge representation scheme used in each layer is discussed in the following.

The working data base stores the input images, the internal CAD-data representation and the intermediate resultant images, the results of processing and making them available to processing algorithms as necessary.

VISIBLE FEATURES AND GEOMETRIC RELATIONSHIPS DEFINITION

This part of the system deals with the segmentation of images and the representation of segmentation results as geometric structure. The representation of segmentation results is iven in Fig. 2 [3]. Segmentation means the decomposition of an image into simple parts. Attributes of these parts, like strenght, centrainty and surface normal are detected. A line or the contour of a region is represented by the chain code or approximated by polylines, splines or straight lines and arcs. Since the system deals with the analysis of three-dimensional scene the information about the shape of the objects is very important.

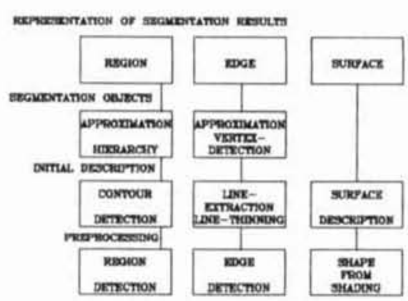

Fig.2

Our goal is to develop an algorithm for recovering the three-dimensional shape of the visible surfaces in a scene from a single two-dimensional image on the base of iterative method [6, 7, 8] for CAD/CAM and vision applications.

Research in shape from shading considers relationship between image brightness and object shape. The relationship between the shape of the object expressed with the normal vector (f,g), in stereograhic plane and brightness E in the respective point of the image can be expressed with the following equation:

$$E(x,y) = R(f,g) \qquad (1)$$

This image irradiance equation is fundamental to the methods for recovering surface shape [7]. This equation gives one constraint. The second is obtained by assuming the surface to be smooth (points which are physically close to each other will have similar normal vectors).

Our objective is to find two functions $f(x,y)$ and $g(x,y)$, that ensure that the image equation, $E(x,y) = R(f,g)$ is satisfied, where $R(f,g)$ is the reflectance map expressed in stereograhic coordinates.

We try to minimize the error in the image irradiance equation:

$$r_{i,j} = (E_{i,j} - R(f_{i,j}, g_{i,j}))^2 \qquad (2)$$

We also try to minimize the error which measures the departure from smoothness at the point (i,j):

$$s_{i,j} = (f_{i,j} - f_{i,j})^2 + (g_{i,j} - g_{i,j})^2 \qquad (3)$$

We seek a set of values { fi,j } and { gi,j } that minimize the total error. The total error can be defined as:

$$e = \sum_{i=1}^{n} \sum_{j=1}^{m} (s_{i,j} + m r_{i,j}) \qquad (4)$$

where m is a constant to adjust the two kinds of error to be in reasonable balance. Equation (4) is minimized by differentiating with respect to f and g. To find f and g we use the relaxation process [7].

$$f^{n+1}_{k,l} = f^{n}_{k,l} + m[E_{k,l} - R(f_{k,l}, g_{k,l})]dR/df$$
$$(5)$$
$$g^{n+1}_{k,l} = g^{n}_{k,l} + m[E_{k,l} - R(f_{k,l}, g_{k,l})]dR/dg$$

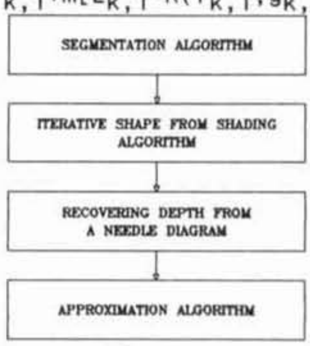

Fig.3

Then we create needle diagram.

We now wish to recover the surface $\{z_{i,j}\}$. To do this, we use an iterative method based on the following relaxation process:

$$z^{n+1}_{k,l} = h/4[(p_{k,l-1} - p_{k,l} + p_{k-1,l-1} - p_{k-1,l}) + (q_{k-1,l} - q_{k,l} + q_{k-1,l-1} - q_{k,l-1})] + 1/4\,(z^n_{k-1,l-1} + z^n_{k-1,l+1} + z^n_{k+1,l+1} + z^n_{k+1,l-1}) \quad (6)$$

We use the method of B-spline interpolation for surface approximation and an graph surface form is created $(z=f(x,y))$.

The whole algorithm of the shape from shading is show in Fig. 3.

According to the objects defined at the begining of this paper different kinds of features are used: edge distribution, region distribution, EGI, surface patch characteristics such as planar, cylindrical, elliptic, or hyperbolic.

On the basis of the needle diagram (surface orientation) we obtain the EGI representation , the Gaussian curvature K and the mean curvature H of the surface as follows:

$$K = (eg - f^2)/(EG - F^2)$$

$$H = (1/2)((eG - 2fF + gE)/(EG - F^2))$$

where E, F, G are the coeficients of first fundamental form and e, f, g are the coeficients of second fundamental form.

Gaussian curvature K and mean curvature H determine the surface characteristic as follows:

1. $K = 0$ and $H = 0$ then planar surface
2. $K = 0$ and $H = 0$ then cylindrical surface
3. $K > 0$ and $H > 0$ then convex elliptic surface
4. $K > 0$ and $H < 0$ then concave elliptic surface
5. $K < 0$ then hyperbolic surface

The characteristics, defined in terms of the Gaussian and mean curvature, are independent of the viewer direction and the rotation.

Surface representations seem ideal for recognizing objects for foollowing reasons:

1. We can still find the equation of a plane even though it is partially hidden.

2. The type of surface patch is fairly stable with respect to variations in the position of the view point.

3. It's possible to choose a description of the surface representation that follows simple rules of transformation when rotated or translated.

When the surface orientation , the affine matrix and the observed region shape are known, the original face shapes can be recovered by the image region shape with the affine transform [10]. Let (p,q) be the surface orientation of one face.

$$T = \begin{matrix} 1+p^2 & (pq)/(1+p^2) \\ 0 & (1 + p^2 + q^2)/(1 + p^2) \end{matrix}$$

gives the affine matrix to recover the original face information from the observed face information. Thus, given (p,q) from shape from shading method we can derive T and transform apparent features to original stored features. For example, the vertex positions are converted to object coordinates using the affine matrix. Then, the corresponding area is examined to determine whether surface pathches having the characteristics exist or not.

The frame describing image domain knowledge, involves all defining features as follows:

Image_feature_rectangular pocket:
RECTANGLE:
AREA_SIZE: size
WINDOW: coordinate
LENGTH: size
WIDTH: size
DEPTH: size
SURFACE TYPE: elliptic surface

KNOWLEDGE ACQUISITION MODULE

The task of component knowledge acquisition is to link the CAD and the Vision system.

As a matter of fact, computer vision algorithms use object feature information to understand the visual word. Therefore, the design feature based scheme is not only useful for the CAD/CAM application [11], but also has general application in the vision information processing area.

The CAD system utilized in this project is AutoCAD (a product of Autodesk, Inc.), which runs on microcomputers but we can construct a vision feature based representation from the ICES or DXF output of any 3-D CAD system [12].

As an experiment we have used a drawing interchange file (DXF), which is an ASCII text file. From surface description (mesch of ponts) we have calculated EGI usable in recognation module

To transform the entities of significance in CAD systems (lines, circles, arcs, etc.) into geometric objects (features) of significance in manufacturing and vision processing we use the presented in [13] method . Initially the DXF file is read and facts are asserted for each entities found in the file: For example, when we described rectangular pocket basic description entites are LINE and CIRCLE.

As a result we describe the design feature (pocket, slot) in the frame called CAD based frame like to image feature frame. This description is usable in recognition module and in the features definition module as well.

RECOGNITION MODULE

The basic concept of presented recognition module is to match image features defined from an image and available CAD-based features for the same object in the knowledge database. The procedural rules control matching process. The basic logic can be explained as follows:

1. The rule calls two frames, image feature frame and CAD-based frame into working memory;
2. The length, Depth and Width are checked first;
3. The rest of the rule is for examining whether the surface has the characteristics describing in CAD based frame. If the inference succeeds, the CAD feature is asserted, the next CAD feature is loaded into the working memory, and the inference goes back to step 2;
4. The procedure repeats until all CAD based features are completed.

INFERENCE ENGINE

The five functions of the inference engine are:

1. Collecting available rules;
2. Scheduling rule-firing seguence
3. Selecting an appropriate rule;.
4. Executing commands defined in the rule;
5. Modifying knowledge database;

The functions 1, 2 and 3 are done in the top layer of metarules, function 2 is related to the knowledge in the second layer and the last function is related to the knowledge in the bottom layer. The layered knowledge database is integrated by the inference engine.

EXPERIMENTS

The image is using TV camera and a computer system for image processing. The size of the image matrix is 256 X 256 and 8 bits per pixel. The equations (5) are solved when the values of parameters are the following: m = 0,001 and e = 0.001. Figure 4 shows the needle diagram for the 3D object and Fig. 5 shows the recovering surface.

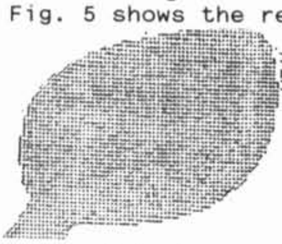

Fig.4

Fig.5

The system consists of several modules and is written in Language C. It runs on microcomputer IBM/PC.

CONCLUSIONS

1. We presented system including shape from shading algorithm, which allows to match CAD model and observed object at many different levels of description (lower or higher level).

2. The system can understand many different parts which are designed with combinations of slots, holls, pockets. The system can be elaborated so that more complex details can be recognized. In this case it's necessary several images from different views of the detail to be analized.

3. The developed system is cheap because it's realized on IBM/PC and use only one TV camera.

REFERENCES

1. A. M. Nadif and M. D. Levine "Low level image segmentation: An expert system "IEEE Tran. Pattern Anal. Mach. Intell. PAMI-6, No.5,p 555, 1984
2. T. Matsuyama, Expert system for image processing, Proc. 9th ICPR, p 125-133, 1988
3. H. Niemann et al, "A Knowledge-Based Vision System for Industrial Applications, "Machine Vision Applications, No.3, p 201-229, 1990
4. T. Matsuyama and V. Hwan, "SIGMA, A framework for image understanding, in proceeding, "9th IJCAI, p 908-915, 1985
5. T. Matsuyama, "Expert System for Image Processing: Knowledge-Based Composition of Image Analysis Processes, "Computer Vision, Graphics and Image Processing, 48, p 22-49, 1989
6. Y. Shirai, Three Dimensional Computer Vision, 1988
7. B. Horn, Robot Vision, 1986
8. .R. Kunchev and M. Milanova, "Recovering Three Dimensional Shape from a Single Image, "ISATA, December, 1990
9. K. Ikeuchi, Horn B.,"Numerical Shape from Shading and Occluding Boundaries, "Artificial Intelligence, 17, No. 1-3, 1981.
10. K. Ikeuchi, "Generation an Interpretation Tree from a CAD Model for 3D-Object Recognition in Bin-Picking Tasks, "International Jornal of Computer Vision, Volime 1, No. 2, pp. 145-167, 1987
11. S. C. Y. Lu and S. Subramanyam, "A computer based environment for simultaneous product and process design, "Advances in Manufacturing Systems Engineering, ASME, III, pp.35-46, November, 1988.
12. National Institute of Standards and Technology, Initial draphics exchange specification, Version 4.0, Tech. Rep., 1988.
13. F. Robert Jacobs, Kieran Mathieson, "A rule-based system to generate NC programs from CAD exchange files, "Computers ind. Engng., Vol. 20, No. 2, pp. 167-176, 1991