J.-D. Dessimoz, M. Kunt, G.H. Granlund and J.-M. Zurcher, "Recognition and Handling of Overlapping Parts", Proc. 9th Intern. Symp. on Industrial Robots, Whashington, DC, March 1979, pp. 357-366 and accompanying video.

RECOGNITION AND HANDLING OF OVERLAPPING INDUSTRIAL PARTS *

J.D. Dessimoz [1]), M. Kunt [1]), G.H. Granlund [2]) and
J.M. Zürcher [1]).

Abstract

In many industrial situations, a robot would be useful to pick parts from containers. This paper deals with the problem of picking the free part on top of the heap with orientation detection. Such an approach is particulary adapted to crooked parts.

Since parts overlap, global properties of objects are not always available. Also, grammar rules dealing with specific heuristic properties need a high teaching effort.

In our method, a curvature function along partly seen contours leads to a good ability to recognize and position objects. In particular, it allows to handle the object on top of the pile. A new preprocessing based on parametrized one-dimensional coordinate filtering makes this approach efficient by drastically improving the features extracted from curves in digitized images.

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[1]) J.D. Dessimoz, M. Kunt and J.M. Zürcher are with the Signal Processing Laboratory of the Swiss Federal Institute of Technology, Lausanne, Switzerland (EPFL).

[2]) G.H. Granlund is with the Electrical Engineering Dept., University of Linkoeping, Linkoeping, Sweden. He was an invited professor at EPFL in 1977, when this work has been initiated.

1. Introduction

The Signal Processing Laboratory of the Swiss Federal Institute of Technology in Lausanne (Ecole Polytechnique Fédérale de Lausanne - EPFL) has been working on industrial robot vision since 1975. This paper presents the latest extensions of our research previously reported in |1|,|2| and |3|.

The basic preprocessing involved in our approach is edge extraction on a digitized image produced by a TV camera followed by an appropriate A to D converter : parts to be recognized and localized are initially represented only by their contours. Then a convenient description of the shape of these contours is performed which must contain the essential feature information needed.

In our previous work, solutions have been found for both the automatic localisation of isolated objects and the localisation and sorting of several non-overlopping objects. When the visual localisation of overlopping parts must be achieved, a number of very restrictive conditions appear. The main ones are the followings :

- Edges of the overlapping parts may be missed because of the poor contrast.
- Some areas of the picture, appearing like blobs and resulting from overlapping, may not represent any actual part.

In agreement with most of the practical situations in industrial part handling, we assume that surfaces of parts are uniform in color. They are not expected to mislead edge extraction because of sharply varying texture.

First, we present in section 2, contour and feature extraction when parts overlap. Section 3 describes how the part on top of the pile is detected and recognized. Then, in section 4, we examine position and orientation estimation for that part. Finally, we conclude with experimental results and remarks.

2. Contour extraction

Acquisition and processing of an image representing overlapping parts require several operations for contour and feature extraction which are briefly described in this section.

2.1 Scene lighting

The first problem is to design an appropriate scene lighting in order to facilitate contour extraction. Since parts have the same color, edges of the overlapping parts may be missed with standard lighting. One possibility is to use several skimming lights placed around the scene. Several images can thus be obtained, each one with a different illumination. Contours can be extracted from each of these images and combined with logical OR's to give the final two-level contour image.

Fig. 1 shows a scene of overlapping parts (1.a), contours extracted with four skimming illuminations (1.b - 1.e) and their combination with a logical OR (1.f). This technique gives satisfactory results on the actual contours even though the contrast is relatively poor on the overlapping parts, but it produces also artificial contour lines induced by shadows. Because of this disadvantage, we have preferred to use a unique illumination and improve the results with subsequent simple processings. Alternative approaches are still under consideration.

2.1 Image filtering

Several contour extracting operators have been described in the literature. While for well-contrasted pictures non linear techniques can lead to ideally thin edges |4|, in poorly contrasted images, very sensitive filters are necessary. Often these filters reveal slight edges where the contrast is poor at the expense of thick outlines where the contrast is good. After various attemps, a simple Robert's operator, i.e. a two-by-two gradient window |4|, has been proved to be satisfactory when used with the tracking procedure described below. An original scene and the resulting contours are shown in Fig. 2.

2.3 Contour tracking

The well-known Freeman's chain code is optimal for describing ideally thin contours. When contours are thick, efficient procedures must be devised. Although, iterative line thinning operators exist, they are usually time-consuming because every picture point should be processed. The method we described here is believed to be more efficient and specially tailored to contour-tracking.

Thick contours are followed side-by-side by two pointers. They move along the contour and keep the minimum distance between them. The "left" pointer moves clockwise to the leftmost neighbour while the other moves counter-clockwise to the rightmost neighbour. Fig. 3 shows the courses of these pointers on an enlarged portion of Fig. 2.b. The mean value of the pointers coordinates gives the skeleton of the curve. When the distance between the pointers grows beyond a given limit, a crossing is assumed to be met. Contour ends and closed contours are also detected when pointers cannot move anymore or when they reach the first initial point of the contour segment. The final result of this algorithm applied to contours of Fig. 2.b is shown in Fig. 4.

2.4 Contour filtering

Digitized contours are affected by noise induced by the cartesian sampling grid. This noise can drastically be reduced by a new iterative curvilinear filtering |5|. Fig. 5 shows the digitized contour of the reference object (5.a) and the result of curvilinear filtering (5.b). An additionnal advantage of this filtering is data compression. Since high frequency components are climinated, the contour can be undersampled, requiring thus very few points (bits) for its storage or representation. The undersampled contour of Fig. 5.b is shown in Fig. 5.c after linear interpolation. The reduction of contour points in this particular case is around four.

3. Detection and recognition of the part on top of the pile

Once the contours are obtained like in Fig. 2.b, the contour tracking method is applied as described in section 2.3. A contour segment is obtained whenever a contour end, an intersection or a closed contour is detected. This segment is curvilinearly filtered, its curvature[1] and its length are computed. Then a test is performed to determine whether the segment length is above or below a given threshold L. If the length is not long enough compared to L, either the segment is dropped because a closed contour, or a contour end has been encountered, or a prolongation of it is searched because an intersection has been detected. In the first case, the same processing is done on a new contour segment. In the second case, the length of the following segment is added to that of the previous one and the result is compared to L. Such a contour prolongation is done untill the total contour length exceed L (see Fig. 6).

The curvature function of the extended segment is cross-correlated with the curvature function of the reference object |3|. The maximum correlation is then compared to a significance threshold. If the test fails (insignificant correlation), a new contour segment is searched. A successful test indicates that the contour segment represents an object possibly overlapped. To determine if the object is indeed overlapped, the contour segment is closed with a number of equally spaced contour points deduced from the reference (Fig. 7). The corresponding locations of these additionnal check points on the contour image (Fig. 2.b) are examined. If these locations have contour points, then the part on top of the pile is detected. In the case of imperfect contour extraction, such a test may be wrongly negative. If the number of check points that do not correspond to contour points in the preprocessed image is sufficiently small, one could consider nevertheless that part as probabily on the top. The risk of a wrong decision should not be too costly, since parts with only a slight overlapping should still be handled without too much trouble.

4. Position and orientation estimation

Position and orientation estimation are described in detail by Dessimoz |3| and will be briefly explained here. The position of an object can be defined by a unique point, independently from any rotation. An obvious choice for this point is the cen-

[1] The curvature is obtained by derivation of tangent angles with respect to the arc length.

ter of mass of the contour segment. Its coordinates are given by :

$$x_{CM} = \frac{\sum_i x_i}{\ell} \qquad y_{CM} = \frac{\sum_j y_j}{\ell}$$

where x_i and y_j are the coordinates of the filtered and regularly resampled contour points and ℓ the length of the contour segment. If another point is required to position the object, its location is obtained by a vectorial addition.

To determine the orientation, a vector $\vec{v}$ is defined by an origin P_1 and an extremity P_2, both on the contour segment (see Fig. 7). This vector is called the orientation vector. The same vector, with the corresponding origin and extremity, is also defined on the reference object of a priori known position and orientation. The relative angle of these two orientation vectors gives the orientation of the observed object.

5. Results and concluding remarks

Digitized pictures used in our study were obtained with a sampling grid of size 128x128. The smallest details of the parts were such that the use of a two-by-two window for contour extraction was quite satisfactory (see Fig. 2.b). The contour extraction is performed in real time by specialized hardware. The processing time required for contour tracking and skeletonization is of the same order of magnitude than that required by the Freeman Code. This efficiency is due to the fact that the pointers examine in average only two neighbours. An interpolation must be performed very rarely to bypass up to two points gaps.

The curvilinear filtering is applied for two iterations with a rectangular window of length 9 grid units. This filtering is necessary to obtain a good curvature estimation, thereby a meaningful correlation. In a first approximation, the quality of the estimated orientation is proportionnal to the length of the contour segment.

The processing time is spent mainly in tracking, filtering and correlating contour segments. With a PDP 11/40, 24 k words memory and a software written in Fortran, this requires about 10 ms per contour point. The method works succesfully with the parts shown in Fig. 2a.

A substantial speed improvement can certainly be gained by performing this algorithm, partly or totally, with a dedicated hardware.

ACKNOWLEDGMENT

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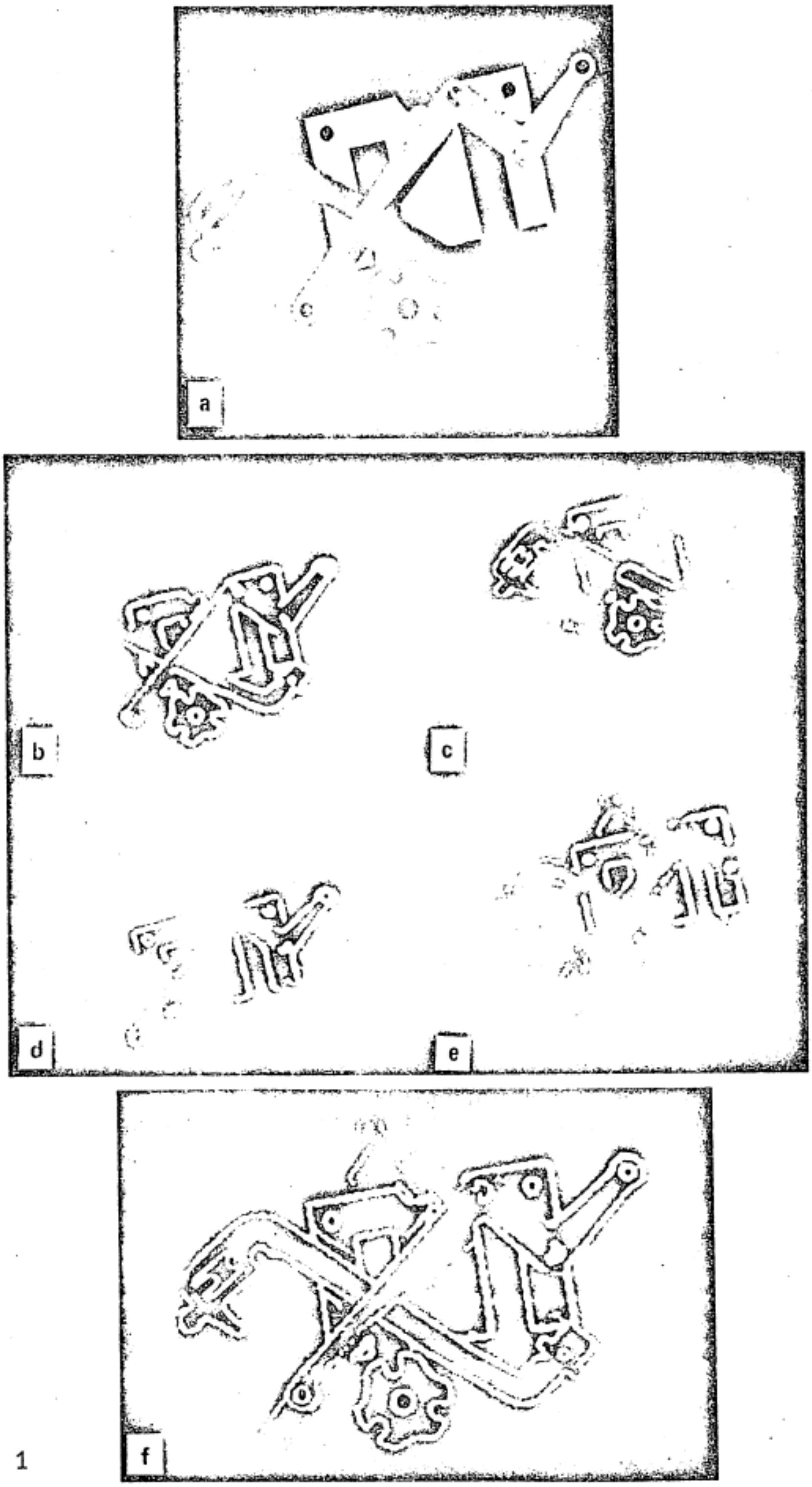

Fig. 1

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"Recognition and handling of overlapping parts"

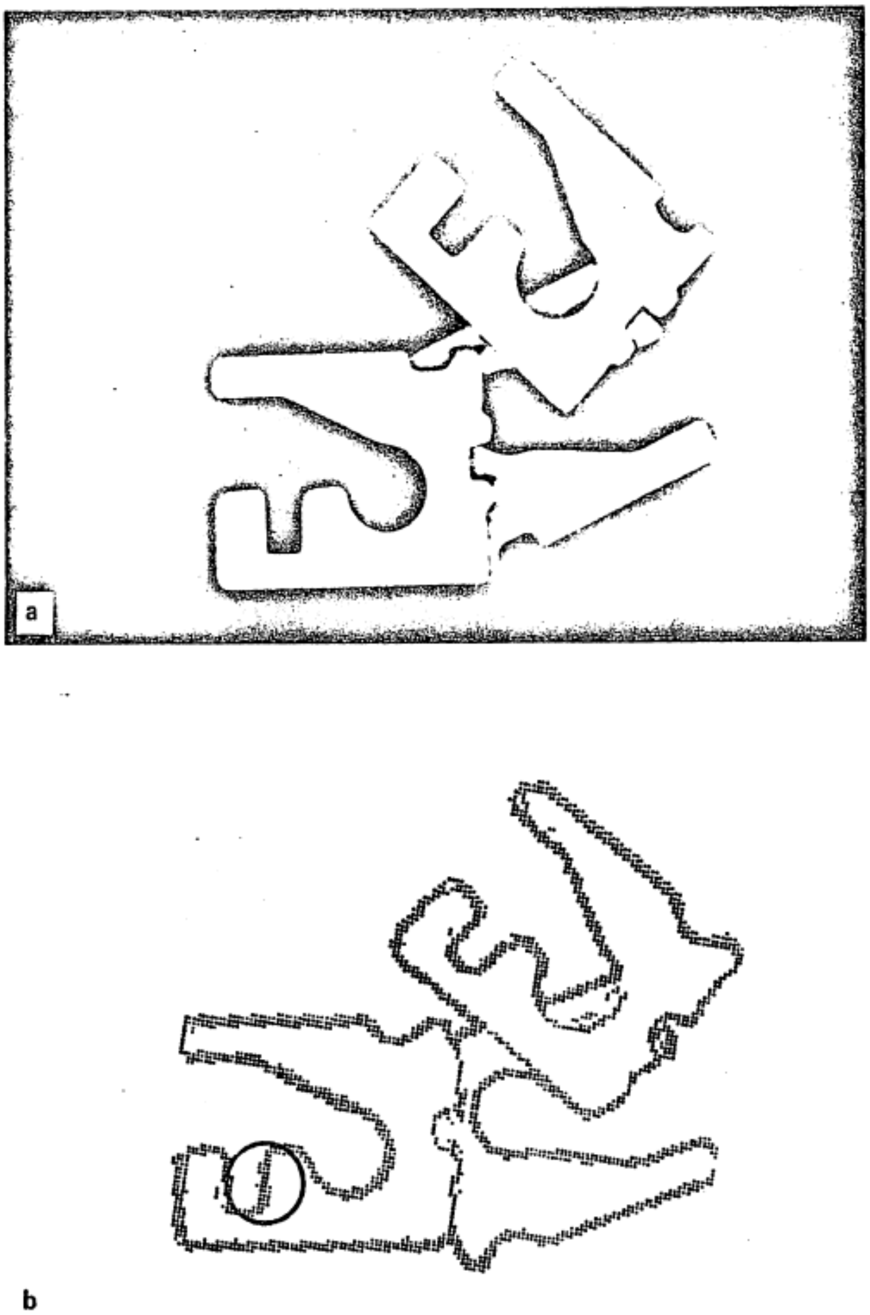

Fig. 2

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"Recognition and handling of overlapping parts"

Fig. 3

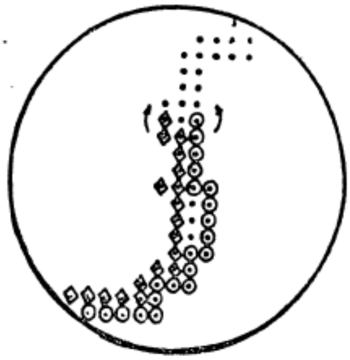
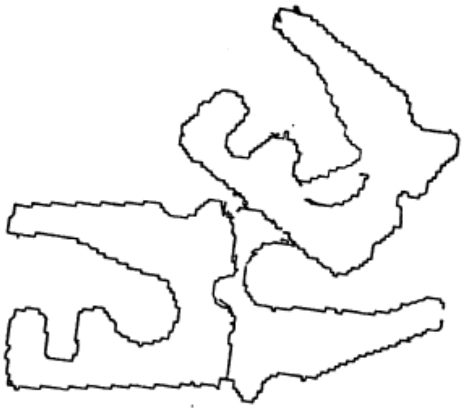


Fig. 4



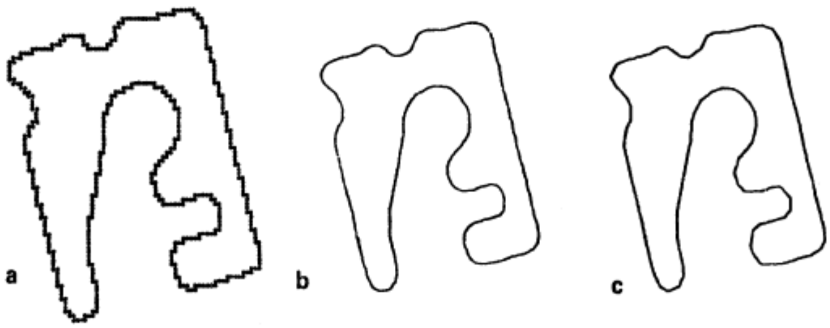


Fig. 5

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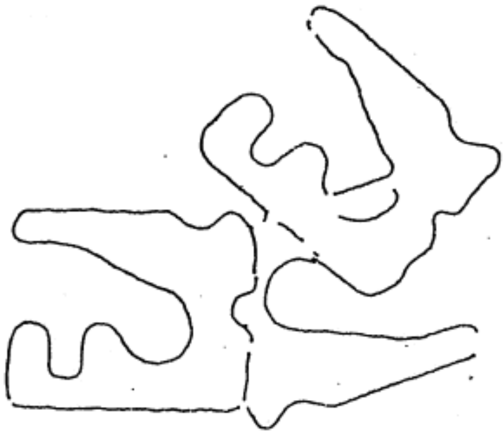

Fig. 6

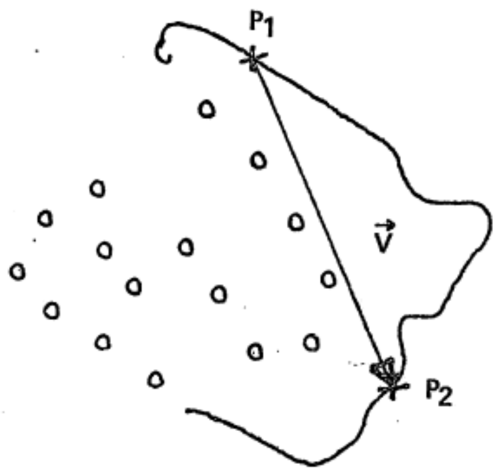

Fig. 7