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A FAST DIGITAL IMAGE PROCESSING TECHNIQUE
FOR OBJECT DETECTION AND CLASSIFICATION

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RESUME

Les algorithmes numériques rapides sont employés dans plusieurs applications du traitement numérique d'images, surtout lorsqu'il s'agit d'analyser beaucoup d'images de grandes dimensions (télé-détection) ou d'applications en temps réel (robotique).

Un ensemble particulier d'algorithmes numériques très rapides est présenté dans cet article pour les applications susmentionnées, en tenant compte surtout de la réduction du bruit et de la détection/classification d'objets.

En ce qui concerne les images obtenues par une caméra de télévision avec une interface de conversion sous forme numérique, quatre problèmes principaux se posent: réduction du bruit; segmentation des séquences; reconnaissance et classification des objets; tracking.

Pour la réduction du bruit, un filtre non linéaire est appliqué ligne par ligne sur l'image, conformément aux relations appropriées. La séparation entre objets et fond s'obtient en utilisant une méthode adaptative qui réduit surtout l'effet des pointes de bruit isolées. Pour la reconnaissance des objets, on extrait les caractéristiques de l'objet comme suit: superficie, position du barycentre, invariants de Fu, axe d'allongement maximal, élongation, etc.

Cette technique complète de traitement numérique d'images a été réalisée en software et largement essayée en utilisant un minicalculateur PDP 11-34 avec une caméra de télévision et une interface de conversion sous forme numérique. Plusieurs expériences ont été effectuées sur différents groupes d'objets statiques ou mobiles. En particulier, 3 à 10 objets mécaniques d'intérêt pratique ont été employés dans l'expérimentation: la détection, la classification et le tracking effectué sur le barycentre ont été parfaitement obtenus.

SUMMARY

Fast digital algorithms are needed in many applications of digital image processing, especially when many images of large size are involved (as in remote sensing) or real-time implementation is required (as in robotics).

A special set of very fast digital algorithms is presented in this paper for the above purposes, with particular reference to noise reduction, object detection and classification.

Making reference to digital images given, for instance, by a TV camera with a digitizing interface, four main problems are encountered: noise reduction; frame segmentation; object recognition and classification; tracking.

For noise reduction a special non-linear smoother is applied line by line, according to suitable relations. The separation among the objects and the background is obtained by using an adaptive method, which reduces the influence of isolated noise peaks. To arrive to object recognition, the object features are extracted as: area, centroid position, Fu's invariants, maximal elongation axis, elongatness, etc.

The above complete digital image processing technique was implemented in software and widely tested by using a PDP 11-34 minicomputer with a TV camera and a digitizing interface. Many experiments were performed on different groups of static or moving objects. In particular 3 to 10 mechanical objects of practical interest were used in the experiments: the detection, classification and tracking (through the centroid following) were perfectly obtained.



1. INTRODUCTION

Fast digital operators and efficient recognition algorithms are of crucial importance for many applications in the area of noisy image processing (communications, remote sensing, biomedicine, recognition of objects and robotics). This is especially true when many images of large size are involved (as in remote sensing) or real-time implementation is required (as in robotics).

Making reference to digital images given, for instance, by a TV camera with a digitizing interface, four main problems are to be carefully considered: noise reduction; image segmentation; object recognition; tracking of moving objects.

In this paper a special set of very fast digital algorithms is presented to solve the above problems. In particular a non-linear smoother is used to reduce noise components and enhance object configurations, while object recognition-classification is performed by means of object inertial-invariant components.

2. NON-LINEAR SMOOTHING AND THRESHOLDING

The use of spatial masks to consider the spatial correlation of each pixel is widely covered in the literature [1][2]. However, the connected processing requirements often pose strong limits to the implementation in on-line systems.

A five-order moving average, moving along a preferential direction, line by line, is here proposed according to the following recursive algorithm

$$\begin{aligned}
 g_{i+1} &= g_i + (f_{i+3} - f_{i-2})/5, \quad i \in [3, 253] \\
 g_1 &= f_1 \\
 g_2 &= (f_1 + f_2)/2 \\
 g_3 &= (f_1 + f_2 + f_3 + f_4 + f_5)/5 \\
 g_{255} &= (f_{255} + f_{256})/2 \\
 g_{256} &= f_{256}
 \end{aligned} \tag{1}$$

where f_i is the original grey level in the i -th position (i -th pixel) and g_i is the new one.

Stating a preferential direction (as horizontal line), non-symmetrical deformations in the original objects in the image plane could result; however, experimental tests have proven that this drawback is not relevant for moving averages of low order (as 3-7). Indeed the above non-linear smoother is reducing noise components and enhancing object configurations.

The separation among the objects under examination and the background is obtained according to an adaptive thresholding rule, based on a look-up table experimentally defined. In particular the mean value

for each line the mean value in a fixed neighbourhood of the absolute minimum of the grey levels of the same line are used. A reduction of the effects of isolated noise peaks is obtained in this way, by establishing an appropriate threshold value to correctly extract the object information. Two pixel subsets are defined: S_o and S_b , corresponding to the pixels which belong to the object and the background, respectively. For each line, a symmetrical band is also established around the mean value of suitable width (selected according to the look-up table): the pixels are hence classified as belonging to S_b if inside this band or to S_o if outside the same band.

Object identification is at this step performed to connect the pixels belonging to the S_o subset previously obtained. A procedure with two sub-steps is used. In the first sub-step, pixel runs for each line are analysed: unique labels are assigned for each run according to the maximum label of the adjacent runs in the previous line (for the first line, progressive labels are set). In the second sub-step, eventual conflicting labels for each connected object are resolved.

3. CLASSIFICATION AND RECOGNITION

According to the previous processing steps, a classification based on the entire object properties is used. Standard parameters, like area M_{oo} , centroid $C(x_c, y_c)$, maximum elongation axis and elongatness are evaluated.

The area M_{oo} and the centroid $C(x_c, y_c)$ are defined by the following relations

$$\begin{aligned}
 M_{oo} &= \sum_{i,j \in O_k} I_k(i,j), \quad I_k(i,j) = \begin{cases} 1 & i,j \in O_k \\ 0 & \text{elsewhere} \end{cases} \\
 O_k : S_o &= \bigcup_{k=1}^N O_k \\
 \text{and } O_k \cap O_l &= \emptyset \text{ if } k \neq l
 \end{aligned} \tag{2}$$

$C(x_c, y_c)$ = centroid position

where $x_c = M_{10} / M_{oo}$, $y_c = M_{01} / M_{oo}$

$$M_{10} = \sum_{i,j \in O_k} I_k(i,j) i$$

$$M_{01} = \sum_{i,j \in O_k} I_k(i,j) j$$

For the definition of the maximum elongation axis and the elongatness, let

$$S = \begin{bmatrix} \mu_{20} & \mu_{12} \\ \mu_{12} & \mu_{02} \end{bmatrix}$$



be the dispersion matrix and

$$\mu_{pq} = \sum_{i,j} \sum_k I_k(i,j) (i-x_c)^p (j-y_c)^q \quad (4)$$

be the central moment of order p,q; then the maximum elongation axis is defined by the line

$$y = y_c + \frac{\hat{\lambda} - \mu_{20}}{\mu_{11}} (x - x_c) \quad (5)$$

where $\hat{\lambda}$ is the greatest root of

$$\lambda^2 - \text{tr}\{S\}\lambda + \det\{S\} = 0 \quad (6)$$

and $\text{tr}\{S\}$ is the trace of S while $\det\{S\}$ is its determinant. The elongateness is defined as

$$\text{elongatness} = (\lambda_2 - \lambda_1) / (\lambda_1 + \lambda_2) \quad (7)$$

being $\lambda_2 \geq \lambda_1$ the eigenvalues of S above defined.

In addition the seven Fu's invariants are evaluated [3]. The recognition is performed, by means of a matching procedure which compares the composition of each object component with a model space.

EXPERIMENTAL RESULTS

The above digital system was implemented in software and widely tested by using a PDP 11-34 minicomputer with a TV camera and a digitizing interface. Many experiments were performed on different groups of objects. In particular 3 to 10 mechanical objects of practical interest were analysed: the recognition and tracking (through the centroid following on moving objects) were perfectly obtained.

Fig. 1 shows an example of object recognition: 5 mechanical objects are shown, as acquired by the TV-digitizing unit. Fig. 2 shows the final result of classification and recognition (different grey-levels are appearing on the objects corresponding to the original different colours on the display): the position of the recognized objects is little different from Fig. 1, corresponding to another image frame.

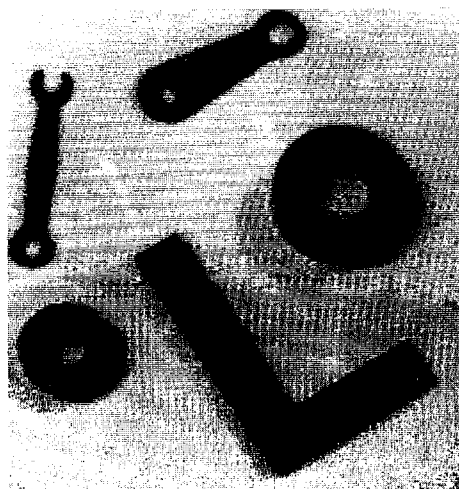


Fig. 1 - Digital acquisition of image with objects.

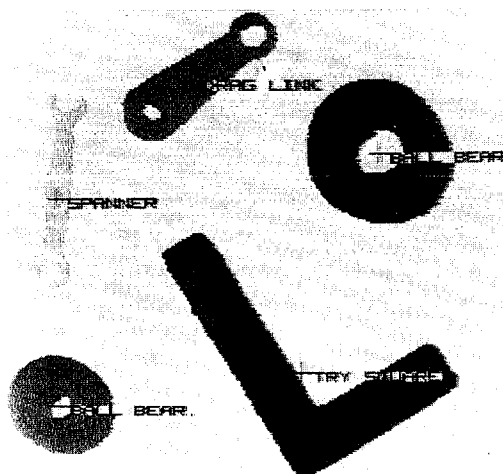


Fig. 2 - Final result of classification-recognition.

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