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OPERATEURS DE FILTRATION NUMERIQUE NON-LINEAIRE POUR LE TRAITEMENT RAPIDE DES IMAGES AVEC BRUIT

NON-LINEAR DIGITAL FILTERING OPERATORS FOR FAST NOISY-IMAGE PROCESSING

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RESUME

Les techniques de filtration rapide sont employées pour beaucoup d'applications dans le secteur du traitement des images avec bruit (communications, relèvement à distance, biomédecine, reconnaissance d'objects en mouvement, robotique). Il est présenté à cet égard trois nouveaux opérateurs numériques rapides non linéaires locaux: le premier opérateur F1 pour l'adoucissement non linéaire, avec réduction des composantes de bruit et des perturbations de faible amplitude; le deuxième opérateur F2 pour la filtration de "fond", avec un accroissement des formes et des configurations utiles; le troisième opérateur F3 pour la filtration non-linéaire des phénomènes isolés transitoires rapides de bruit ou des impulsions de scintillation.

Il est souligné en particulier comment l'emploi de l'opérateur F1 avant et des les opérateurs F2-F3, après la détection usuelle des contours (ED), peut assurer une extraction très efficace des contours et des limites dans les images avec bruit traitées; le bruits et les perturbations de différente nature (casuels, par rafales, transitoires) sont considérablement réduits, tout en préservant toutes les données utiles concernant les contours et les limites.

Comme exemple typique, il est présenté dans les détails l'application des opérateurs précités dans un système pour la reconnaissance d'objects en mouvement. Ce système, après les opérations F1, ED, F2, F3 susmentionnées, exécute une segmentation des contours des objects, une analyse circulaire des contours (après détermination du "centroide") et la FFT des distances de ces contours du centroide. La reconnaissance finale est obtenue à travers la comparaison des modules FFT évalués (pour l'invariance rotationnelle) avec les valeurs FFT mémorisées (correspondant aux objects à reconnaitre). Il est rapporté des expériences de reconnaissance et porsuite de plusieurs objects mécaniques qui se déplacent sur une surface plate, expériences qui ont été effectuées en utilisant un minicalculateur et une caméra de télévision avec une interface de conversion en chiffres at qui confirment la grande efficacité du système en question, dérivant surtout de l'utilisation des trois techniques de filtration numérique non-linéaire susmentionnées.

SUMMARY

Fast filtering techniques are required for many applications in the area of noisy-image processing (communications, remote sensing, biomedicine, recognition of moving objects and robotics). Three new non-linear fast local-space digital operators are presented for this purpose: the first operator F1 to perform non-linear smoothing, reducing low amplitude noise components and disturbances; the second operator F2 to perform a "background" filtering, enhancing the useful patterns and configurations; the third operator F3 to perform non-linear filtering of isolated noise "spikes" or "scintillation" pulses.

In particular it is outlined how the use of the operator F1 before and of the operators F2-F3 after usual edge detection (ED) is giving high efficiency extraction of edges and boundaries in the processed noisy images: noise and disturbances of different nature (random, burst, spike behaviour) are greatly reduced, preserving however all useful information data regarding the edges and the boundaries.

As a typical example, the application of the above operators in a system for moving object recognition is presented in details. The system, after the above operators F1, ED, F2, F3, performs a segmentation of the object boundaries, a circular scanning of the boundaries (after "centroid" determination) and FFT of the boundary distances from the centroid. The final recognition is obtained through the matching of the evaluated FFT modules (for rotational invariance) with memorized FFT values (corresponding to the objects to be recognized). Experiments of recognition and tracking of several mechanical objects, moving on a flat tape, performed by using a minicomputer and a TV camera with a digitizing interface, are reported, confirming the high efficiency of the developed system, due in a great part to the use of the three non-linear digital filtering operators.

Operateurs de filtration numerique non-lineaire pour le traitement rapide des images avec bruit

Non-linear digital filtering operators for fast noisy-image processing

1. INTRODUCTION

Linear digital operators are well known for image processing: an output image is formed from linear combinations of data (pixel values) of an input image. Such linear operations include for instance: superposition, convolution, unitary transformations, discrete linear filtering [1] . These operations are useful for several usual image processing applications.

Non-linear digital operators are however more and more often required in the image processing area, both for compensating non-linear transformations and degradations in the image formation and for increasing the processing speed. These non-linear operators are indeed very interesting for fast noisy image processing in such fields as communications, remote sensing, biomedicine, recognition of moving objects and robotics.

Some non-linear operators have been already introduced and applied in digital image processing: homomorphic filtering for image restoration when an observed image is subject to multiplicative interference or degradations [2] ; median filtering for noise reduction [3]; non-linear edge enhancement methods [4] .

In this paper some special non-linear digital filtering operators are presented for fast noisy-image processing, giving in particular high efficiency extraction of edges and boundaries in the processed images. As a typical example, the application of these operators in a system for moving object recognition is shown, reporting some experimental results obtained by means of a minicomputer system with a TV camera and a digitizing interface.

2. SOME SPECIAL NON-LINEAR DIGITAL OPERATORS

A first non-linear digital operator F1 performs a smoothing, reducing low amplitude noise components and disturbances. The detailed structure of the operator we defined is a suitable variation of the operator proposed by Rosenfeld [5] . According to Fig. 1, the gray level at each pixel P_0 is replaced by the average of itself and the values in the neighbourhood, except those which have gray level differences greater than a fixed threshold in absolute value. The updated value of P_0 is given by

$$P'_0 = \frac{1}{n} \sum_{P_i \in S} P_i \qquad (1)$$

where $S = \{P_i : |P_i - P_0| \leq k_1\}$ and $i=0,1,\ldots 8$.

P_4	P_3	P_2
P_5	P_0	P_1
P_6	P_7	P_8

Fig. 1 - Position of the pixels with the gray level values P_i in the image to be processed.

This operator F1 has the following interesting properties:

- in a homogeneous region, noise components, such that their differences are less than k_1, are smoothed; near a boundary or edge, whose contrast is greater than k_1, any pixel around the edge is not included in the average evaluation (this allows a smoothing of the pixel values on either seide of the edge without any damage for the edge itself, as a linear smoothing usually would do).

Further this non-linear filtering procedure can be iterated to obtain better results (greater noise reduction in the processed image). Another important parameter is represented by the size of the operator (or mask dimension): by applying masks larger than 3·3, as above, the number of iterations is decreasing (2 iterations of a 9·9 operator produce similar results to 8 iterations of a 3·3 operator with the same threshold value k_1). After several simulations and experimental tests, we found that 2 iterations of a 3·3 operator are in general sufficient to obtain good results.

A second non-linear digital operator F2 performs a filtering of isolated noise spikes (or scintillation pulses), essentially represented by high noise levels concentrated in 1 or 2 pixels. Again with reference to Fig. 1, let us denote with P_m the average of the gray levels of the pixels in the neighbourhood of P_0, that is

$$P_m = \frac{1}{8} \sum_{i=1}^{8} \qquad (2)$$

The operator F2 is working according to the following principle: if all pixels P_i $(i=1,2,\ldots 8)$ have a gray level differing from P_m less than a suitable threshold k_2 and P_0 has a gray level differing from P_m more than $k_2+\Delta$ (with $\Delta \geq 0$), the value of P_0 is set equal to P_m; otherwise P_0 maintains its original value.

For a binary image, as obtained with threshold criteria or after the application of an edge detector, the operator F2 can be defined through the following relations

$$\text{if } P_0 = 0 \quad \begin{cases} P'_0 = 0 & \text{if } \sum_{i=1}^{8} P_i \leq n_m \\ P'_0 = 1 & \text{otherwise} \end{cases} \qquad (3)$$

$$\text{if } P_0 = 1 \quad \begin{cases} P'_0 = 0 & \text{if } i \in \{1,2,\ldots 8\} : P_i = P_j = 0 \\ & \text{where } j=i+1 \text{ if } i<8 \\ & \text{and } j=1 \text{ if } i=8 \\ P'_0 = 1 & \text{otherwise} \end{cases} \qquad (4)$$

If in the relation (3) $n_m=7$, the operator essentially changes the value of the central pixel P_0 if its gray level is different from those of the 8 pixels around, having all these 8 pixels the same value. With $n_m<7$, the central value 0 is changed to 1 also if not all the 8 pixels around have the value 1.

The above non-linear operator F2, working with the described decision criterion, permitts to reduce noise spikes and local irregularities: small holes are filled and irregularities of boundary curves are reduced. Larger masks than the above 3·3 are not practically useful due to the neglegible efficiency increase and higher computing complexity and cost.

A third digital operator F3 performs a filtering of background noise and can be especially useful when patterns and configurations of limited extension are to be extracted. One working procedure of this operator corresponds to evaluate the average of the gray levels of the pixels in a suitably extended image region and to subtract this average from the pixel gray levels. In the case of dynamic scene analysis, when subsequent images are taken (for instance by a TV camera) on a fixed space region where some objects are moving or configurations are changing in time, a simple working procedure of the operator consists in performing the difference of the gray levels of corresponding pixels in the subsequently acquired images, that is

$$f_d(n_1,n_2) = f(n_1,n_2,n_3+k_3) - f(n_1,n_2,n_3) \qquad (5)$$

where $f(n_1,n_2,n_3)$ is the image available at some time instant t, $f(n_1,n_2,n_3+k_3)$ is the image at a subsequent time instant $t+\tau$ and $f_d(n_1,n_2)$ is the obtained image difference.

The above described non-linear digital operators are very useful when edge detection is to be performed on the available images. In this case the use of the operator F1 before and of the operators F2-F3 after usual edge detection ED is giving high efficiency extraction of edges and boundaries in the processed noisy images: noise and disturbances of different nature (random, burst, spike behaviour) as extended or local degradations are greatly reduced, preserving however the useful information data, especially regarding the edges and the boundaries.

3. APPLICATION IN A SYSTEM FOR MOVING OBJECT RECOGNITION AND TRACKING

As a typical example, the application of the above digital operators in a system for moving object recognition and tracking is presented in the following.

In the developed system no a-priori knowledge is assumed about size, shape, texture and stationary or non-stationary components of analyzed images. The used recognition method is essentially based on edge detection and FFT evaluation on the distances of the object boundaries from the object centroid. The operator F1 is used before edge detection ED, while the operators F2-F3 are applied after ED, as above outlined.

The main processing steps of the implemented system are the following ones.

1. Learning phase, including the acquisition and the modelling of the objects which are to be recognized (FFT modules of the object boundaries are memorized).
2. Pre-processing of the images by means of a non-linear smoothing (operator F1), reducing low amplitude noise components and disturbances.
3. Edge detection through a modified Sobel algorithm, as defined in Fig. 2.

$$\begin{matrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{matrix} \qquad\qquad \begin{matrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{matrix}$$

Fig. 2 - Definition of x (at left) and y (at right) components of the used edge detector.

4. Moving object detection: non-stationary components of the image sequences are separated from stationary ones (background filtering by means of the operator F3, extracting the useful configurations corresponding to the moving objects).
5. Post-processing, performing (by means of the operator F2) a non-linear filtering of isolated noise spikes or local irregularities (the value n_m=6 in the relation (3) is in general used).
6. Image segmentation, representing the silhouettes of the moving objects in a two-level code (Freeman type code).
7. Object modelling: only the shape of the silhouettes of the detected objects are considered (interior part is ignored); a circular scanning of the object boundaries from the object centroid is performed and the FFT of the boundary distances from the centroid is evaluated.
8. Object recognition: a matching is performed between the memorized FFT modules and those actually evaluated on the image sequence (FFT modules are indeed used to obtain a rotational invariance, that is a correct recognition for any rotation of the objects in the image plane) by means of minimum distance criteria.
9. Tracking of the moving objects, through the determination, as above outlined, of the object centroids and eventually prediction of subsequent estimated positions of object centroids.

The recognition system defined by the above processing steps 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 moving objects. In particular 3 to 5 moving mechanical objects of practical use were analyzed: the recognition and tracking were perfectly performed.

Some examples related to three mechanical objects, moving on a flat transporting tape, are shown in Fig. 3.

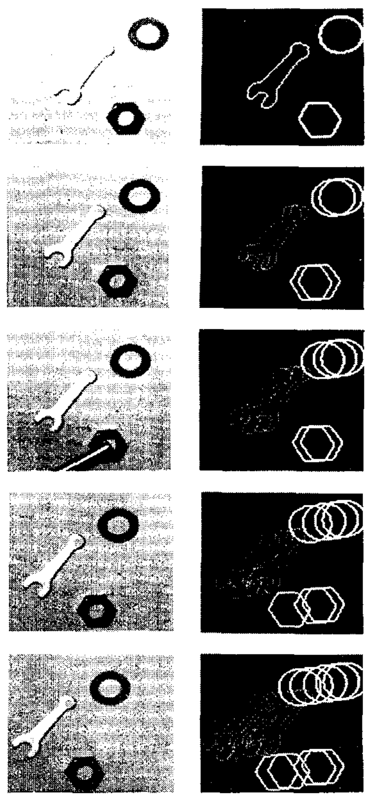

Fig. 3 - Object recognition example in five subsequent movements of three mechanical objects (spanne, nut, washer): at left the digitized images are shown, while at right the recognized objects are appearing (on display each one with a different color).

In the left part of the image, from the top to the bottom, five subsequent movements of a spanner, a nut and a washer are shown in the digitized images as acquired by the minicomputer system. In the right part of the image the recognized objects are shown at each movement step on the color display connected to the system (each object has a different colour, for instance red, yellow and white). In the third movement step a disturbing object of cylindrical shape is overposed on the nut: as it is appearing at right the overall new object is now not recognized and the correct performance of the system is confirmed (if required, the actual third position of the nut could be predicted or estimated from the preceding ones, by means of the tracking algorithm).

It is important to outline how the good efficiency of the above presented recognition system (using quite standard edge detection and recognition algorithms) is in great part due to the use of the three non-linear digital filtering techniques (F1,F2, F3) which are fast and able to reduce noise, disturbances and other image degradations.

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