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SOME HIGH EFFICIENCY DIGITAL TECHNIQUES FOR REMOTE SENSING DATA PROCESSING

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Abstract

Some efficient digital techniques, based on digital filtering, local space operators and data compression algorithms, are presented for remote sensing data processing. In particular it is described how by means of two-dimensional digital filters it is possible to perform enhancement and noise reduction on the remote sensing images, improving their quality. Further it is shown how by means of some local space operators it is possible to extract boundaries and edges to perform with pattern recognition algorithms a clear identification and classification of different image parts. Some data compression techniques are also described to reduce the amount of data solving handling and storage problems. Two techniques, one based on digital filtering and decimation the other on data compression algorithms, are hence presented for comparison and correlation of earth maps obtained from sensors at different heights (aboard aircrafts, satellites). Applications of the above techniques are finally shown to process aircraft photos and LANDSAT images for agriculture and water resource evaluations.

1. INTRODUCTION

Remote sensing data, as received from earth resource satellites or obtained through analog-to-digital conversion of aircraft photos, are to be processed by means of suitable digital techniques to correct the data, to improve their quality and to obtain final useful results.

In this paper some efficient digital techniques, based on digital filtering, local space operators and data compression algorithms, are presented for remote sensing data processing. In particular the following digital techniques are presented: two-dimensional digital filters to perform enhancement and noise reduction improving data quality; local space operators to extract boundaries and edges to obtain a clear identification and classification of different image parts; data compression techniques to reduce the amount of data solving handling and storage problems. Two new techniques, one based on digital filtering and decimation the other on data compression algorithms, are hence presented for comparison and correlation of earth maps obtained from sensors at different heights (aboard aircrafts, satellites).

Examples of application of the above techniques are finally shown to process aircraft photos and LANDSAT images for agriculture and water resource evaluations.

2. TWO-DIMENSIONAL DIGITAL FILTERS

A two-dimensional (2-D) digital filter can be defined through the following relation [1]

$$g(n_1,n_2) = \sum_{k_1=0}^{N_1-1} \sum_{k_2=0}^{N_2-1} a(k_1,k_2) f(n_1-k_1,n_2-k_2) - \sum_{k_1=0}^{M_1-1} \sum_{\substack{k_2=0 \\ k_1+k_2\neq 0}}^{M_2-1} b(k_1,k_2) g(n_1-k_1,n_2-k_2) \qquad (1)$$

where: $f(n_1,n_2)$ are the input data (digital samples of the analog image for a photo), $g(n_1,n_2)$ are the output data (samples of the output image), $a(k_1,k_2)$ and $b(k_1,k_2)$ are the coefficients defining the 2-D frequency response of the digital filter, N_1 N_2 M_1 M_2 are integers.

Many types of 2-D digital filters have been defined: with finite impulse response (FIR) of non-recursive type having all $b(k_1,k_2)=0$; with infinite impulse response (IIR) of recursive type [1] .

Some important design methods of 2-D FIR digital filters are: methods using "windows"; frequency sampling methods; approximation methods. Filters of this type can present good efficiency (in particular linear phase characteristics) and relatively simple hardware and software implementation: they are useful and practical for many actual digital processing applications to remote sensing data.

A relatively simple technique is represented by the window method: desired filter impulse response is truncated and its samples $(h(k_1,k_2)$ are multiplied by suitable correction factors $w(k_1,k_2)$, which are samples of the used window function. Recently an high-efficiency window was introduced (Cappellini window): the 1-D form of this window (2-D form can be easily obtained through rotation) has the property of giving a minimum value of the uncertainty product in a modified form. Resulting FIR 2-D digital filters have higher efficiency than other known filters using windows in a wide range of required characteristics [1] .

Some approaches to design 2-D IIR recursive digital filters are: differential correction methods; factorization methods; rotation methods (from 1-D to 2-D). These approaches and other ones are up to now not so well defined as FIR methods, due to the difficulties of factorizing 2-variable transfer functions and to the resulting problems of designing filters with sufficient accuracy and stability. Therefore, while from a theoretical view-point IIR filters can have higher efficiency than FIR filters (requiring a lower number of coefficients), they are not so easily available for digital processing of remote sensing data. An interesting method, as described in [2] , is based on transformations of the squared magnitude function of 1-D digital filters to 2-D domain (through the McClellan transformation [1]) and uses a suitable decomposition in four stable filters.

2-D digital filters, as above described, can be applied to remote sensing data processing to smooth the data (by means of low-pass filtering) or to perform frequency correction or to obtain enhancement (by means of high-pass or band-pass filtering) extracting also edges and boundaries. In particular through smoothing a reduction of high space frequency noise can be obtained, while through enhancement better quality images are in general resulting.

3. DATA COMPRESSION TECHNIQUES

Data compression is a transformation performed to reduce the amount of not useful or redundant data. Several data compression techniques have been introduced of reversible and not reversible type (reversible means that the inverse transformation or decompression can recover all the original data).

Some important data compression techniques are: prediction, interpolation, adaptive sampling, encoding, filtering, use of transformations (Fourier, Hadamard, Walsh, Haar, Slant...) [3] . All one-dimensional data compression technique can also be applied to image processing, if the image is scanned line by line.

Let us consider in particular prediction-interpolation techniques, use of digital filtering and use of transformations.

In the process of prediction the knowledge of preceding samples is used while in interpolation the knowledge of preceding and subsequent samples is utilized. In both types of operation the predicted or interpolated sample is compared with the actual one: if the resulting difference is within the allowable error tolerance, then the prediction or interpolation is considered correct and the actual sample is eliminated. Otherwise the actual sample remains in the compressed data.

For what regards digital filtering, 2-D digital filtering of low-pass or band-pass type represents by itself a sort of data compression, because a limited part of the space frequency spectrum is extracted, requiring a lower number of data to be maintained. Further 2-D low-pass digital filtering can be used as an useful pre-processing before the application of eventual other compression algorithms, because the smoothed data can be more efficiently compressed.

For what regards the use of 2-D transformations, their interest is connected to the fact that the transformed data are in general more concentrated than the original space data and hence are more easily compressed. Some useful methods [3] consist in dividing the transformed image data into several squares of small size (4x4, 8x8, 16x16) and in employing for each of them a minimum word length.

The interest of applying data compression techniques to remote sensing data processing is due to the fact that an extremely large amount of data is already now and more in the future given by the sensors aboard aircrafts or satellites making difficult and sometimes impossible to handle the data and to storage for subsequent utilization.

4. LOCAL SPACE OPERATORS

Several space operators have been defined which process the image data directly in the space domain, in general without consideration of the space frequency behaviour.

Of particular interest are digital operators performing Kalman filtering and 3x3 operators. The first ones are useful to process noisy images (as photos degraded by foggy conditions or similar ones) and are particularly efficient when the noise characteristics are known or well estimated. The second operators process 3x3 blocks of data, in general obtaining the new central data from suitable processing of the other ones.

The operators of the second type are particularly useful to obtain boundaries or edges through gradient estimation. Two main types are known: one based on the use of suitable processing masks (Prewitt, Kirsch, Robinson, Chen Frei), the other based on the evaluation of the two orthogonal components of the gradient D_x and D_y and hence of its value through the relation

$$D = \sqrt{D_x^2 + D_y^2} \tag{2}$$

with a direction given by

$$\alpha = \mathrm{arctg}(D_y/D_x) \tag{3}$$

Two interesting algorithms to evaluate D_x and D_y are: Sobel method, isotropic gradient method [4] .

The above 3x3 local space operators are very useful for edge extraction from remote sensing images to perform different parts determination and land-use classification.

5. TECHNIQUES FOR COMPARISON AND CORRELATION OF MAPS OBTAINED FROM DIFFERENT SENSORS

An important practical problem in processing remote sensing data is represented by the need of comparison and correlation of maps obtained from different sensors, in particular at different height.

Two new techniques are here presented, one based on the use of 2-D digital filtering and decimation, the other based on compression techniques.

For what regards the first technique, let us consider two maps $f_1(n_1,n_2)$ and $f_2(n_1,n_2)$ - the first with high resolution (low altitude of sensor), the other with low resolution (high altitude of sensor) - and apply the following processing procedure:

- perform a low-pass 2-D digital filtering with a cutoff frequency

$\omega_c/(2\pi) = 1/(2X_2)$, where X_2 is the space sampling interval of the $f_2(n_1,n_2)$ map, in such a way to obtain the filtered map $g_1(n_1,n_2)$;

- reduce or "decimate" the obtained data $g_1(n_1,n_2)$ to a space sampling interval equal to X_2, that is obtain the map $g_2(n_1,n_2)=g_1(n_1X_2, n_2X_2)$.

The above operations take out from the 2-D spectrum of the high resolution map $f_2(n_1,n_2)$ all the space frequency components greater than $\omega_c/(2\pi)$ giving a map which is comparable as resolution to the low resolution $f_2(n_1,n_2)$ [5] .

The second technique uses a compression method (as prediction or interpolation, in particular of adaptive type) to reduce the high resolution map to the definition of the other one: in particular a weighted interpolation is applied [5] .

6. EXAMPLES OF APPLICATION OF THE DESCRIBED DIGITAL TECHNIQUES TO PROCESSING OF REMOTE SENSING DATA

Three examples of application of the described techniques to processing remote sensing data are given in the following: the first uses 2-D digital filtering on aircraft photo, the second applies local space operators and thresholding classification on aircraft photos, the third shows data compression on LANDSAT data.

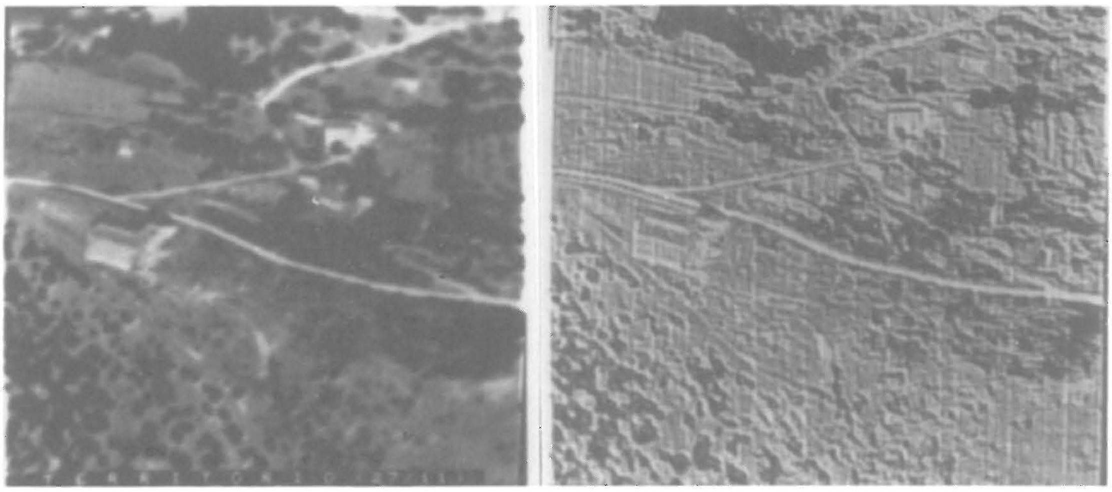
Fig. 1 shows an example of application of a 2-D FIR high pass digital filter to an aircraft photo (in cooperation with Istituto di Elettrotecnica e Elettronica of Trieste University): in (a) the original reconstructed image (after digital-to-analog conversion) is shown, while in (b) the processed image is given. More details and structures are emerging from the processed data, useful for classification or archaeological investigations (the region, Capaccio in central Italy, is rich of archaeological structures).

Fig. 2 shows an example of application of local space operators (isotropic gradient method on 3x3 data blocks) after a smoothing: in (a) the original photo (an agricultural region at the South of Florence) is presented, in (b) the edge extraction after smoothing is shown, in (c) three classes are given (forest at left, wine-grape and olive plants in the middle and ather land at right).

Fig. 3 shows an example of application of zero-order interpolator (ZOI) as compression technique to a LANDSAT image (in the central Italy): in (a) the original image is given with 10 grey level representation, in (b) the reconstructed image after the application of ZOI is given, requiring an amount of data less than half of the original one (a small detail degradation is observed). Higher data amount reduction were obtained by using Fast Walsh Transform [3] but with greater processing cost.

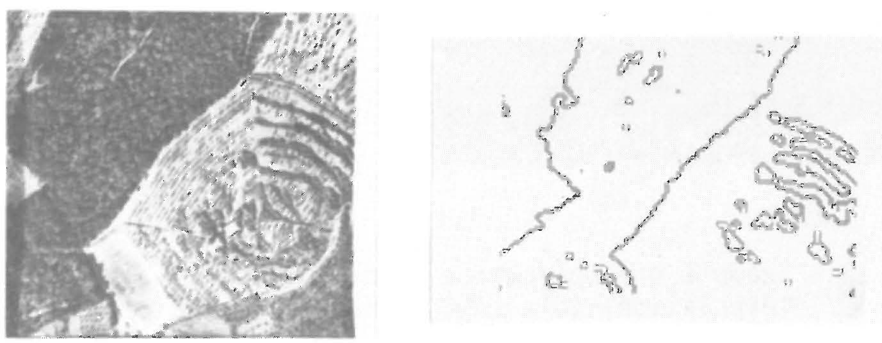
As the above examples show, the interest of using the described techniques for processing remote sensing data is resulting to perform image enhancement, edging, classification and data compression. These techniques were by us applied to agriculture investigations, water resource evaluations and archaeology [6] [7] .

The described digital techniques open new areas of work on remote sensing data, which can be used in conjunction with the more classical analog methods of photo-interpretation and image analysis. With the reducing cost of digital processing, both in software (minicomputers, microprocessors) and hardware, the advantages of these digital techniques, which surely are more flexible and efficient, are more and more resulting for photogrammetry and remote sensing investigations.

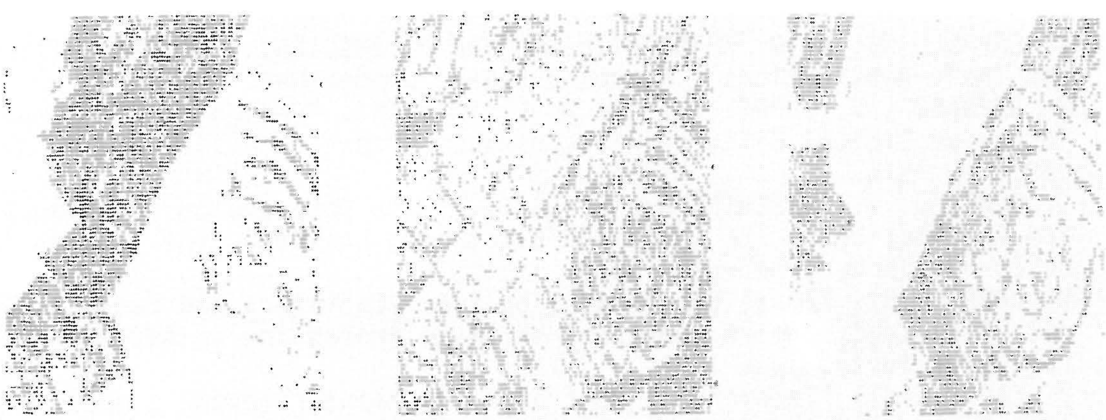


(a) (b)

Fig. 1 - Example of application of high-pass 2-D digital filtering to an aircraft photo: (a) original; (b) processed image.



(a) (b)



(c)

Fig. 2 - Example of application of local space operators with smoothing to aircrfat photo: (a) original, (b) edge extraction, (c) classification in forest (at left), wine-grape and olive plants (in the middle) and other land (at right).

(a)

(b)

Fig. 3 - Example of application od data compression (zero order interpolation) to a LANDSAT map: (a) original; (b) compressed map.

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