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WORKSHOP ON REMOTE SENSING TECHNIQUES WITH APPLICATIONS TO AGRICULTURE, WATER AND WEATHER RESOURCES

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DIGITAL COMPARISON AND CORRELATION TECHNIQUES OF REMOTE SENSING IMAGES WITH DIFFERING SPATIAL RESOLUTIONS

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ABSTRACT

Some digital techniques are proposed to compare and correlate remote sensing images having different space resolution. To compare high space resolution images with other images having lower resolution, a procedure is presented based on the use of a suitable low-pass digital filtering applied to the high resolution image and subsequent data reduction to obtain an image comparable with the lower resolution one. To pass from low space resolution images to higher resolution ones, two "estimation" techniques are proposed: spectral extrapolation performed on the space frequency spectrum of the low resolution image; approximated Shannon interpolation performed on the low resolution image, followed by "re-sampling" procedure. Some practical examples are given, regarding LANDSAT and SEASAT images.

Keywords: Digital Processing Techniques, Remote Sensing Images, Comparison and Correlation, Different Space Resolution.

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, to perform a clear "interpretation" and to obtain final useful results.

An important practical problem in processing the above remote sensing data is represented by the need (more often emerging) of comparing and correlating images and maps obtained from different sensors, in particular at different height or with different ground space resolution. Some typical examples on this line are represented by: aircraft photos (high ground space definition in the order of 1 meter or less); LANDSAT images and SEASAT images (medium ground space definition in the order of 30-80 meters); HCMM or METEOSAT maps (low and very low ground space definition).

In the following some digital techniques are proposed to compare and correlate different sensor images and maps as above, passing from high to lower resolution or definition and viceversa.

2. TECHNIQUES TO COMPARE HIGH RESOLUTION IMAGES WITH LOWER RESOLUTION ONES

Let us consider two images, $f_1(n_1,n_2)$ and $f_2(n_1,n_2)$ in digital form, the first with high ground space resolution or definition and a space sampling interval X_1 (distance at ground corresponding to the extension of one "pixel" along the orthogonal x-y axes), the second with lower ground space resolution and a sampling interval $X_2>X_1$. Practically, if $m=(X_2/X_1)$, to one pixel of the image $f_2(n_1,n_2)$ correspond m^2 pixels of the image $f_1(n_1,n_2)$.

Several approaches can be used to obtain from high definition image $f_1(n_1,n_2)$ an image $g_1(n_1,n_2)$, having the space sampling interval X_2 equal to that of the lower definition image.

A first simple technique corresponds to evaluate $g_1(n_1,n_2)$ data as the usual average of $f_1(n_1,n_2)$ data, that is (with m odd)

$$g_1(n_1,n_2) = \frac{1}{m^2} \sum_{k_1=-\frac{m-1}{2}}^{\frac{m-1}{2}} \sum_{k_2=-\frac{m-1}{2}}^{\frac{m-1}{2}} f_1(n_1-k_1,n_2-k_2) \quad (1)$$

The $g_1(n_1,n_2)$ image obtained in this way represents a rough "smoothed" version of the original high definition image $f_1(n_1,n_2)$.

A second more refined approach consists in evaluating $g_1(n_1,n_2)$ data as a "weighted" average of $f_1(n_1,n_2)$ data, that is

$$g_1(n_1,n_2) = \sum_{k_1=-\frac{m-1}{2}}^{\frac{m-1}{2}} \sum_{k_2=-\frac{m-1}{2}}^{\frac{m-1}{2}} w(k_1,k_2) f_1(n_1-k_1,n_2-k_2) \quad (2)$$

The weights $w(k_1,k_2)$ in the above relation define the form of "smoothing" operation which is performed on the $f_1(n_1,n_2)$ data: it is easy to verify, for instance, that with $w(k_1,k_2)=(1/m^2)$ the relation (2) is equivalent to the relation (1). It can appear reasonable to give, in general, a greater weight to the central pixels of the m·m sub-image of $f_1(n_1,n_2)$ image with respect to the peripheral ones: to this purpose one solution corresponds to use a linear weighting resulting into a conical (or pyramidal) function in the 2-D domain; another solution consists in using a Gaussian weighting function (the 2-D function can be easily obtained through the circular rotation of 1-D Gaussian function).

The above described techniques perform a "smoothing" operation on the high definition image $f_1(n_1,n_2)$ in a "heuristic" way to obtain the image $g_1(n_1,n_2)$ to be compared and correlated with the lower definition image $f_2(n_1,n_2)$. A more rigorous and precise digital technique, we have recently proposed and defined (Ref. 1-2), is based on the use of a 2-D digital filter of low-pass type with circular symmetry (Ref. 3). A digital filter of this type can be in general defined by the following relation

$$g_1(n_1,n_2) = \sum_{k_1=0}^{N_1-1} \sum_{k_2=0}^{N_2-1} a(k_1,k_2) f_1(n_1-k_1,n_2-k_2) - \sum_{\substack{i_1=0 \\ i_1+i_2\neq 0}}^{M_1-1} \sum_{i_2=0}^{M_2-1} b(i_1,i_2) g_1(n_1-i_1,n_2-i_2) \qquad (3)$$

where $a(k_1,k_2)$ and $b(i_1,i_2)$ are the coefficients defining the digital filter frequency response and N_1,N_2,M_1,M_2 are suitable positive integers. If in the relation (3) all $b(i_1,i_2)$ coefficients are zero, the 2-D digital filter is called of non-recursive type or FIR digital filter (having a finite impulse response), otherwise it is called of recursive type or IIR digital filter (having an infinite impulse response).

There are several methods to design 2-D FIR or IIR digital filters (in particular of low-pass type with circular symmetry): a useful method to design FIR digital filters corresponds to the use of suitable "window" functions defining the final expression of the $a(k_1,k_2)$ coefficients; an interesting and efficient method to design IIR digital filters is based on transformations of the squared magnitude function of 1-D digital filter to 2-D domain and decomposition in four stable digital filters (Ref. 3). An example of a 2-D IIR digital filter of this last type, requiring in overall 38 independent coefficients, is shown in Figure 1.

The precise steps of this digital technique, using a 2-D digital filter of low-pass type with circular symmetry, are the following ones:

- to perform a low-pass, circular symmetry, 2-D digital filtering, as expressed by the relation (3), with a cutoff frequency $\omega_c/(2\pi)=1/(2X_2)$, obtaining the filtered image $g_1(n_1,n_2)$;
- to reduce or "decimate" the obtained data $g_1(n_1,n_2)$ up to a space sampling interval equal to X_2, that is to obtain the image (in digital form) $g_2(n_1,n_2)=g_1(n_1X_2,n_2X_2)$.

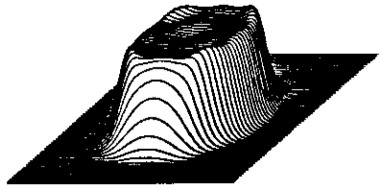

Figure 1. Example of frequency response of a 2-D IIR digital filter of low-pass type with circular symmetry.

The above digital operations indeed take out from the 2-D spectrum of the high definition image $f_1(n_1,n_2)$ the space frequency components greater than $\omega_c/(2\pi)$, giving therefore an image which is directly comparable - for what regards the space definition or resolution - to the lower definition image $f_2(n_1,n_2)$. The two digital images $g_2(n_1,n_2)$ and $f_2(n_1,n_2)$ result actually to have gray level variations in the different space directions with the same maximum angular space frequency.

It is interesting to observe that the 2-D digital filter used in this last rigorous and precise digital technique includes, as indeed particular cases, the digital operators defined in the relations (1) and (2): the first is obtained by the relation (3), by setting $b(i_1,i_2)=0$ and $a(k_1,k_2)=(1/m^2)$; the second is resulting by setting $b(i_1,i_2)=0$ and $a(k_1,k_2)=w(k_1,k_2)$.

3. TECHNIQUES TO COMPARE LOW RESOLUTION IMAGES WITH HIGHER RESOLUTION ONES

From an information point of view, this situation represents a much more difficult problem than the previously considered one, due to the fact that now we try to define, or better to "estimate", a higher resolution image from an image having lower resolution. In general, it is not possible to solve this problem in a rigorous or precise way, but useful "estimations" or "approximations" can be obtained: two techniques are described in the following.

A first technique corresponds to use the Shannon interpolation (Ref. 3), according to the following steps:

- to perform a truncated Shannon interpolation on the low resolution image $f_2(n_1,n_2)$ to obtain a continuous image $f_2(x,y)$;
- to perform a "re-sampling" of the image $f_2(x,y)$ with a space sampling interval equal to X_1, obtaining the sampled image $g_2(n_1,n_2)$ having the same space resolution or definition as the image $f_1(n_1,n_2)$.

In practice the two above operations can be performed through a single digital operation, corresponding to use the truncated Shannon interpolation in which the continuous {sinc} functions are sampled with a space interval equal to X_1.

A second technique is based on "spectral extrapolation" procedures. Due to the fact that the low resolution image $f_2(n_1,n_2)$ has a limited spectrum extension (the maximum space frequency being anywise limited to the value $1/(2X_2)$), these procedures try to extrapolate this spectrum, extending it to higher space frequencies. To this purpose, extrapolation relations of first, second or higher order can be used: in a simpler way these relations can be applied in 1-D form along the two space frequency axes; in a more rigorous way the extrapolation is applied in 2-D form.

3. CONSIDERATIONS FOR THE PRACTICAL USE OF THE DESCRIBED TECHNIQUES AND SOME EXAMPLES OF APPLICATION

The above described digital techniques can be practically used to compare and correlate different sensor images and maps, passing from high to lower resolution or definition and viceversa.

As already observed, the first techniques (from high to lower resolution) solve in a good way the problem, due to the fact that sufficient information is available in the high resolution image $f_1(n_1,n_2)$ to obtain the $g_1(n_1,n_2)$ image to be compared with $f_2(n_1,n_2)$ one. The techniques with the relations (1) and (2) are very simple and fast; the techniques with the procedure using a 2-D low-pass digital filter are little more complex but have higher efficiency.

The second techniques (from low to higher resolution) represent only an "attempt" to solve a very difficult problem, due to the lack of sufficient information in the low resolution image $f_2(n_1,n_2)$. The Shannon interpolation technique is of more general use for any kind of $f_2(n_1,n_2)$ image, while the spectral extrapolation technique can be more useful when the value of the m "scaling factor" is relatively small or some "a-priori" information is available on the spectrum of the $f_2(n_1,n_2)$ image.

For the practical application of the above digital techniques some other important operations are to be performed, due essentially to the fact that the two images $f_1(n_1,n_2)$ and $f_2(n_1,n_2)$ have been obtained by sensors aboard space vehicles (aircraft or satellite) at different space position (different coordinates and angles of view): geometrical corrections and rotations with change of the point of view are therefore in general required (Ref. 4).

As typical examples, the application of some of the above techniques to LANDSAT C images (X_2=80m) and SEASAT images (X_1=30m) is presented in the following, regarding a costal region in the South Italy (Sele river in Campania).

Figure 2 shows the SEASAT-SAR image (256x256), while Figure 3 shows the LANDSAT image (256x256). Figure 4 reports the result of the 2-D digital filtering (low-pass type, circular symmetry) of the SEASAT image (according to the above theory). Figure 5 shows the two final images obtained: at left is the LANDSAT image (a part of the original image suitably rotated, to be "registered" with the SEASAT image); at right is the SEASAT filtered image already "decimated" (corresponding to $g_2(n_1,n_2)$). Figure 6 shows a simple "integration" attempt: at left the "addition" and at right the "difference" are given of the two finally obtained images.

For what regards the second type techniques, Figure 7 shows the result of Shannon interpolation applied to the LANDSAT image (arriving now at the same space definition of the SEASAT image) suitably rotated. Figure 8 shows a simple "integration" attempt, corresponding to the "addition" of the obtained LANDSAT map and the original SEASAT map, while Figure 9 shows the "difference" of the two maps.

The above examples confirm the good performance of the proposed digital techniques for the digital comparison and correlation of remote sensing images having different space resolution or definition. When the final maps, in homogeneous space sampling format, have been obtained, several "integration" procedures can be applied to produce maps having "higher" information content for specific utilizations of remote sensing data (the simple addition or difference integration here shown is only a part of the many integration possibilities).

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4. REFERENCES

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Figure 2. SEASAT-SAR image (256x256), regarding a costal region in the South Italy (Sele river in Campania.

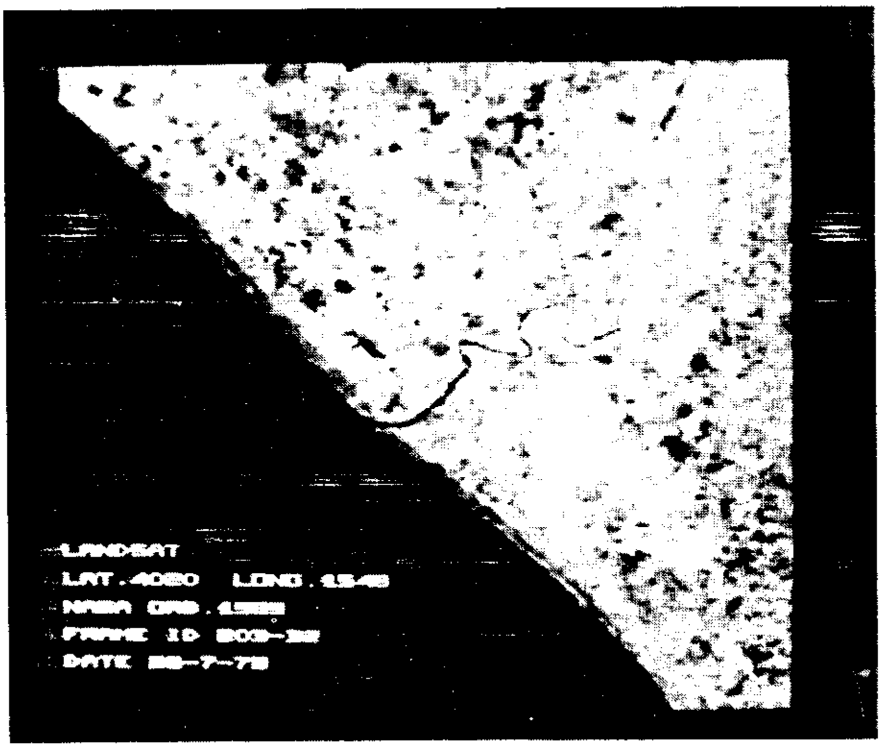

Figure 3. LANDSAT image (256x256), regarding the same costal region in the South Italy as the Figure 2.

Figure 4. Result of the 2-D digital filtering (low-pass type, circular symmetry) of the SEASAT image.

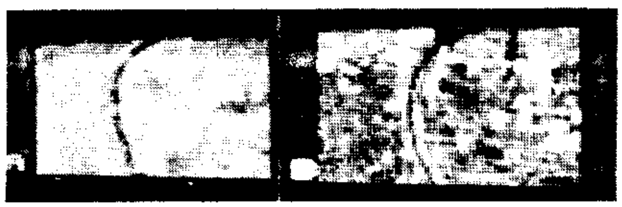

Figure 5. The two final images obtained for comparison and correlation: at left is the LANDSAT image (a part of the original image suitably rotated to be registered with the SEASAT image); at right is the SEASAT filtered image already decimated.

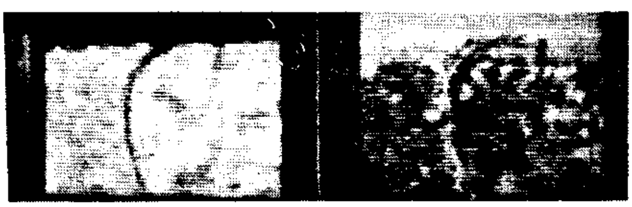

Figure 6. A simple integration test: at left the addition and at right the difference are given of the two finally obtained images.

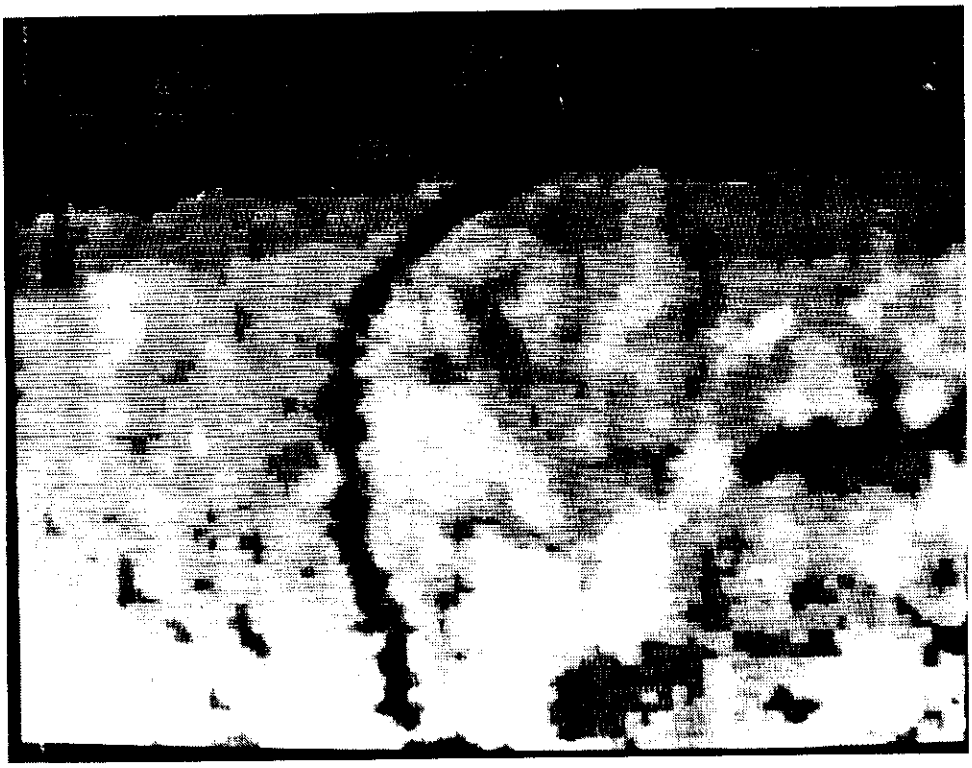

Figure 7. Result of Shannon interpolation applied to the LANDSAT image (arriving now at the same space definition of the SEASAT image) suitably rotated.

Figure 8. A simple integration test: the addition of the obtained LANDSAT image and the original SEASAT image is shown.

Figure 9. Another simple integration test: the difference of the two final images is shown.