ON THE TECHNIQUE FOR TERRAIN ROUGHNESS DETERMINATION

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ABSTRACT

In analogy with electric signal, the roughness of terrestrial relief can be defined as a component similar to the noise present at the signal during the transmission process. According to this concept, the paper presents a technigue of the roughness determination using spectral analysis of dense sampled terrain profiles. The periodogram is used to make it evident. It aids to find out roughness specific frequency. Afterwards, the separation of the roughness is achieved by filtration process in the frequency domain, carried out with Butterworth filter, followed by inverse Fourier transform. The results obtained are illustrated through the graphical representations and the comparisons made between the initial profiles and the filtered profiles.

1.INTRODUCTION

The terrestrial relief is a complex spatial surface with a high degree of variability, that includes in this structure different types of forms. From the geomorphologic point of view, the relief form is the descriptive element of the particular aspects of the terrestrial surface, according to the genesis. Besides genesis, that is considered an element of great importance, different parameters that describe their geometric features are used for the analysis of relief forms. It is obvious that the number of proposed parameters for this aim is considerable. Based both on the describing capacity of terrain variations and on the easiness of application of some modern analysis methods, respectively of classification, three parameters are considered to be most significant out of the multitude of parameters : the dimension or the vertical amplitude (relief), defined as the value differences of the height extreme values, the slope standing for the first order derivative of the height and wawelenght or the mean distance between successive extreme local heights of terrain profile (Frederiksen. P, Jacobi. O, Kubik. K, 1984).

The relief form in geomorphological space, evaluated from the geometric point of view, under their dimentional aspect or as size order, cover a very large range. Thus, according to G-scale used in a taxonomic hierarchic classification based on the size order and the geometric topological complexity (Dikau. R, 1990) in geomorphological space, there are: mega ($> 10^{12}$ mp), macro (10^{12} - 10^{8} mp), meso (10^{8} - 10^{4} mp), micro (10^{4} - 10^{0} mp), nano (10^{0} - 10^{-4} mp) and picoforms ($< 10^{-4}$ mp). The roughness or the small size terrain variations can be included in nanoform classes, taking this hierarchy as refference.

The terrestrial surface is a suming (superposition) of components of different sizes and configurations, viewed from the structural point of view. Its representations under profile form, reveals spatial development of this similar to the variations of an electrical signals. If a comparison of different components conformly to this is performed, the roughness can be asimilated with the present noise in the structure of the signal during transmission process. Described according to the above mentioned parameters, within the signal theory context, it represent the random variations of very little amplitude and period or high frequency relief.

Considering the analogy between terrain profile and electrical signal as main hypothesis, the paper presents a technique of roughness determination with the specific means of spectral analysis.

2. ROUGHNESS DETERMINATION USING SPECTRAL ANALYSIS

Spectral analysis has numerous applications in different domains of science and technique. It forms a distinctive chapter with theoretical basis within modern measurig techniques. Its use in the field of photogrammetry, includes mainly applications connected with the digital elevation models (DEM) technologies. A short survey points out: the interpolation interpretation, smoothings and parametrical transformations as types of discrete convolution (Kratky. V, 1980), sampling interval determination (Jacoby. O, 1980, Kraus. K, 1984, Hassan.M.M, 1986), data filtering (Hassan.M.M, 1988a, 1988b) and accuracy of DEM' s estimation (Frederiksen. P, Jacobi. O, Justensen. J, 1978, Frederiksen. P,1981, Jacobi. O, 1980, Tempfli. K, 1980, 1982, Frederiksen.P, Jacobi. O, Kubik. K, 1984) , terrain types classification (Ayeni. O, 1976, Jacobi. O, 1980, Frederiksen. P, Jacobi. O, Kubik. K, 1984), slope and terrain curvature mapping (Papo. H. B, Gelbman. F, 1984).

The main operating tools from spectral analysis represented by series and Fourier transforms have the capacity of achieving a link between the domain of signals existence (space or time) and frequency, domain in which the signals can be represented. Simultaneously with this special property, Fourier transform have the property of being able to be used at the identification of some signals of different frequency, additively combined and then, because it enable the spectral estimation obtaining, at their separation through filtering operations.

The applications of these concepts at the study of relief components, on an analysis process is based, within which samples of a finite lenght signal (0,L), Zi terrain heights are considered. Their uniform gathering along profiles to the univariate analysis mode corresponds and respectively bivariate, if by sampling strategy in the structure of a network also uniform, are distributed.

Directly and indirectly submited to Fourier transformation, the heights values lead to the obtaining of spectral estimates, which in ensemble form the power spectrum. The magnitude of spectrum values render the energetical levels corresponding to height samples, therefore implicitly to terrain variations, offering in a first variant the possibility of this characterising by " power " (energy). Consequently, ordered according to their frequency in a spectrogram (periodogram), will be the frequency content descriptor and at the same time, an efficient and objective means for different types of the forms existing in the studied terrain pointing out.

2.1 Power Spectrum Estimation

At present, the spectral analysis uses two methods to obtain the power spectrum. The indirect method or the "standard " method (Blakman - Tukey) conceived on the basis of Wiener - Hinchine relations, which express the property that correlation function and power spectrum form Fourier paires, and the direct method (Cooley - Tukey). In the first case the spectral estimation result indirectly, through Fourier transformation applied to the correlation function values, and the second case as a result of Fourier transformation application starting directly from the measured Zi heights samples. It is worth mentioning that in both cases, the use of fast Fourier transformation (FFT) procedure has a prevailing importance.

The direct method was chosen in the experiment, aiming to the easiest calculation effort. Its implementation was done in a program of processing which uses a fast Fourier transformation subroutine.

A brief description of this method presents the following characteristics. The input data are represented by terrain heights reduced to a trend function ($\overline{Zn}$ = Zn - T) for the spectrum values calculus or for the spectral density function. Then according to the overall strategy the X(jf) amplitude spectrum is determined and subsequently the power spectrum:

$$G(jf) = \frac{1}{L} \left[X^*(jf) * X(jf) \right] = \frac{1}{L} \mid X(jf) \mid^2 \qquad (1)$$

Smoothing opperations are required because the estimations of amplitude spectrum will be affected by errors due to truncate effect (the terrain profile have a L limited lenght).The smoothness can be performed at a level of amplitude spectrum or at the power spectrum level. One of the weighting methods which operates spatially or frequentially is used in this situation.

If Z(s) is a terrain profile with L lenght, sampled a Δs interval, process that issues Zn (n=0, N-1) row of heights, after their reduction to the trend function, the spectral lines are determined as follows:

$$X(jq) = A(q) - jB(q)\ ; \quad (q = 0, Q-1) \qquad (2)$$

where X(jq) is the spectral amplitude density, q the order of spectral line, A(q) the real component and B(q) the imaginary component. According to the sampling theorem the integral frequency content is obtained only when fe sampling frequency is conforming with the condition:

$$f e \geq f max \qquad (3)$$

Taking into account the relation; L = (N - 1) Δ s = (N - 1) / f e, respectively f max = (Q - 1) Δf, in which Q represents the total number of spectral lines, and f= 1/ L, the spectrum resolution, results that the Q $\simeq$ N/2 relation exists at the limit of the fulfilment of (3) condition, between N-the number of height samples and Q. Thus the periodogram must include N / 2 spectrum lines to describe the frequency range as accurately as possible.

It was already mentioned that the spectrum estimations obtained in the first phases are affected by errors consequent to the use of finit profile. The limitation at a finit interval of variable which represents in this case the terrain haights is equal with a filtration in the space domain.Thus the terrain profile is assimilated with a truncate signal representing the product between Z(s) real signal and spatial filter. The physical process, through which adjacent spectral lines values, intervene for a spectral line due to truncation in calculated spectrum, having as effect the introduction of an error, is called in technical literature leakage (Davenport.W.B, Root.W.L, 1958). The solution of convolution with Henning weighting window d(n) = 0.5 * [1 + cos (2πn/N)]; n = 0, N-1 applied to frequency, was used in order to eliminate. According to addopted solution the components of raw spectral lines which have following expresion:

$$A(q) = \Delta s \sum_{n=0}^{N-1} Z(n) \cos (\pi qn / Q)$$

$$B(q) = \Delta s \sum_{n=0}^{N-1} Z(n) \sin (\pi qn / Q) \qquad (q=0,Q-1) \qquad (4)$$

are ajusted by relations:

A(0) = 0.5A(0) + 0.5A(1)
B(0) = 0.5B(0) + 0.5B(1)
- - - - - - - - - - - - - - - - -
A(q) = 0.25A(q-1) + 0.5A(q) + 0.25A(q+1)
B(q) = 0.25A(q-1) + 0.5B(q) + 0.25B(q+1) (5)
- -
A(Q-1) = 0,5A(Q-2) + 0.5A(Q-1)
B(Q-1) = 0.5A(Q-2) + 0.5B(Q-1)

Then, the spectrum values are obtained using the relations:

$$G(q) = \frac{1}{L} \left[A^2\ (q) + B^2\ (q) \right]\ ;\ (q=0, Q-1) \qquad (6)$$

The periodogram curve is drawn by using them, out of wich (fr) frequency level corresponding to roughness is selected. This will be the main parameter or (fc) cut-off frecvency used during the filtering process through which the high frequency relief components are separated from the other terrain forms.

2.2 Roughnes Components Filtering

Filtering is a commonly used procedure in signals processing techniques. It consist mainly in retaining certain component parts of a signal, when it passed through the filter or window. In their numerical variant the filters are described mathematically by an P[ ] operator, which converts $Z(n\Delta s)$ input signal in $z(n\Delta s)$ output signal;

$$z(n\Delta s) = P\,[Z(n\Delta s)] \qquad (7)$$

achieving filterig functions of lowpass type, highpass, bandpass and bandstop. According to P[ ] operator properties different filter classes can be achieved. Invariant in space (or time), linear systems have the largest use, because they allow a easier mathematical treatement.

The condition of linearity as well as that of invariance are imposed to the operator in order to get these systems (Hamming. R. M, 1977). According to the first condition, if $z1(n\Delta s)$ and $z2(n\Delta s)$ represent the filter respons to $Z1(n\Delta s)$ and $Z2(n\Delta s)$ input samples, the filter is linear only when:

$$\begin{aligned} P\,[\,aZ1(n\Delta s) + bZ2(n\Delta s)\,] &= \\ = aP\,[\,Z1(n\Delta s)\,] + bP\,[\,Z2(n\Delta s)\,] &= \qquad (8) \\ = az1(n\Delta s) + bz2(n\Delta s) & \end{aligned}$$

where a and b are dwo arbitrary constants. The second condition require that the filtering effect be the same irrespectively of the filtered sample position. Thus if the respons to $Z(n\Delta s)$ input sample is $z(n\Delta s)$, then respons to $Z((n-k)\Delta s)$ sample will be $z((n-k)\Delta s)$.

h(n) is considered the result of the transformation obtained through the application of P[ ] operator to $\delta(n)$ impulse signal:

$$h(n) = P[\,\delta(n)\,] \qquad (9)$$

Also, P[ ] operator is applied to the signal expressed by the relation:

$$P[\,Z(n)\,] = P[\,\sum_{i=1}^{N} Z(i)\,\delta(n-i)\,] \qquad (10)$$

By using the linearity condition, (10) becomes:

$$z(n) = \sum_{i=1}^{N} Z(i)\, P[\,\delta(n-i)\,] \qquad (11)$$

The following relation results taking into account of invariance condition:

$$z(n) = \sum_{i=1}^{N} Z(i)\,h(n-i) = \sum_{i=1}^{N} h(i)\,Z(n-i) = h(n) * Z(n) \qquad (12)$$

where the second equality is obtained from the (n-i) -> i change of variable and third represents the shortening form.

The relation (12), called also the convolution sum, proves that a space invariant and discrete linear filter is entirely characterised by its respons to signal impulse. Thus knowing h(n) kernel, by computing the convolution sum with input data Z(n), will result z(n) filters respons.

The z(n) response values can be obtained by directly calculating the convolution sum. But this method means an important operation volume because N multiplications are necessary for each Zi height sample. The cutting of operations number is achievsd by using fast Fourier transformation algoritms. Thus , if $\mathcal{F}[\,z(k)\,]$, $\mathcal{F}[\,Z(k)\,]$ and $\mathcal{F}[\,h(k)\,]$ are Fourier transforms corresponding to z(n), Z(n) and h(n), can be write:

$$\begin{aligned} \mathcal{F}[\,z(k)\,] &= \mathcal{F}[\,h(k)\,] * \mathcal{F}[\,Z(k)\,] = \\ &= H(k) * F(k) \qquad (13) \end{aligned}$$

and respectively:

$$\begin{aligned} z(k) &= \mathcal{F}^{-1}\{\,\mathcal{F}[\,h(k)\,] * \mathcal{F}[\,Z(k)\,]\} = \\ &= \mathcal{F}^{-1}[\,H(k) * F(k)\,] \qquad (14) \end{aligned}$$

(13) and (14) relations associated to a fast Fourier transformation (FFT) algorithm implemented in a subroutine lead to the following operating procedure: $\mathcal{F}[\,h(k)\,]$ and $\mathcal{F}[\,Z(k)\,]$ discrete Fourier transforms are computed at a begining, then $\mathcal{F}[\,h(k)\,] * \mathcal{F}[\,Z(k)\,]$ product is done and finally z(k) respons filter is determined through inverse Fourier transformation (Stolojanu. G, Podaru. V, Cetina. F, 1984).

In this approach context, the roughness is determinated through a filtering process, frequentially achieved, in which $\mathcal{F}[\,h(k)\,]$ transform or H(k) is reffered as process transfer function, respectively as of the applied filter.

Butterworth filter was chosen for filtering execution, starting from idea to use fr frequency level corresponding to roughness, that main factor within terrain data processing. The reason of this choise is that it poses a transfer function which offers possibility of being directly conditioned to operate taking into account this parameter. It is used as low frequency filter, having fc cutt-off frequency equal to fr for the separation of components which represents terrain roughness.

The transfer function for Butterworth lowpass filter (BLPF) of n order is given by the relation:

$$H(jf) = 1 \,/\, [\,1 + (f/fc)^{2n}\,] \qquad (15)$$

(fc = cutt-off frequency)

Grafically represented for n = 1, has the form show in figure 1:

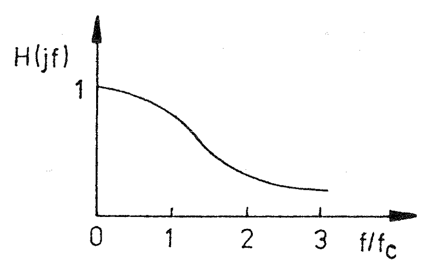

Fig. 1 The transfer function of the Butterworth' s filter (n=1)

The analyse of function graphic reveals that it cannot strictly define the separation between filtered frequency and unfiltered ones. That is why the place of fc cutt- off frequency is established in a position for which H(jf) is smaller with a certain fraction than its maximum. A common value used is $(1/\sqrt{2})\,H(jf)_{max}$. Changed in this sense, relation (15) will have the following form (Gonzalez. R. C, Wintz. P, 1987) :

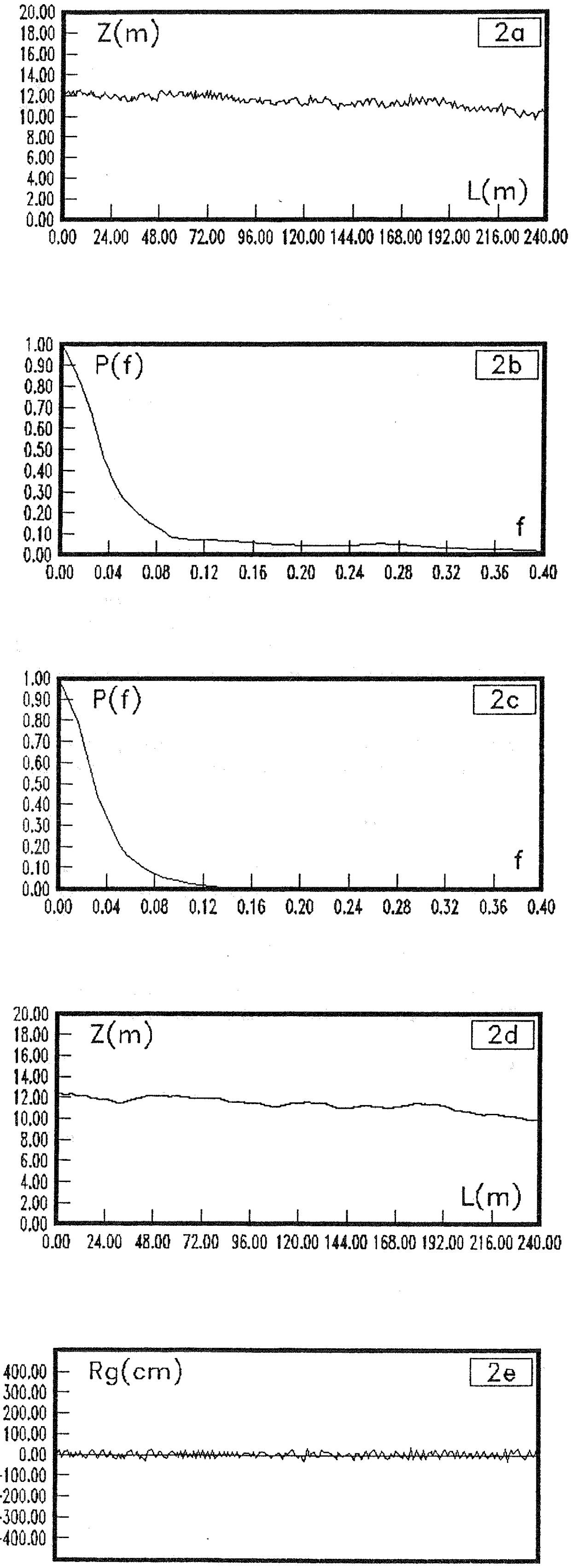

Fig. 2. Roughness determination in a plane terrain

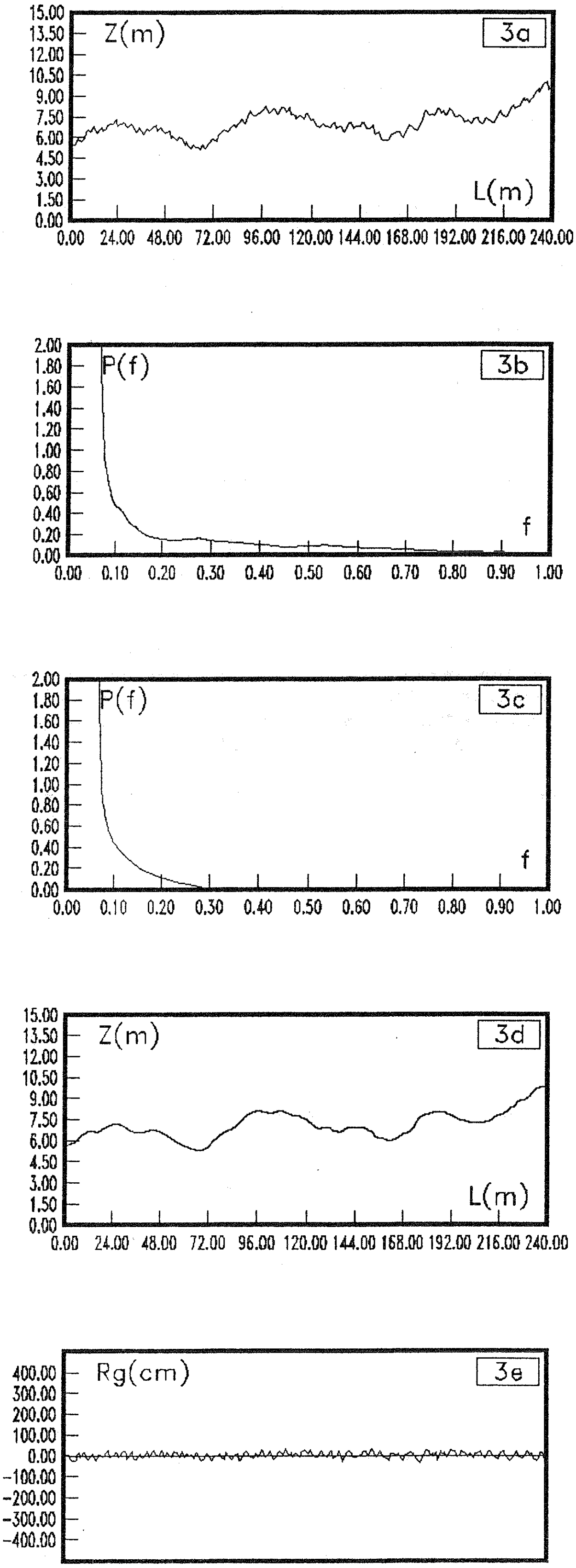

Fig. 3. Roughness determination in a moderate variable terrain

$$H(jf) = 1 / [1 + (\sqrt{2} - 1)(f/fc)^{2n}] =$$

$$= 1 / [1 + 0{,}414 (f/fc)^{2n}] \quad (16)$$

After obtaining filtered profiles, by their subtract from initial profiles, the heights differences (dhr_i) which represent the roughness values, are determinated. As parameter for global caracterisation of the roughness, root mean square (rms) height differences is used:

$$e = [\Sigma (dhr_i)^2 / N]^{1/2} \quad (17)$$

3. RESULTS AND CONCLUSIONS

Efficiency of periodogram use in height informations analysis has been demonstrated within the studies concerning detection and filtering of errors in DEM' s data (Hassan. M. M, 1988a, 1988b), The application of its highlights properties of the parts in a signal to the question of determining roughness or high frequency relief, is based on some observation as follows:

-power spectrum estimations corresponding to low frequencies (fig. 2b and 3b) convey in periodogram curve, the contribution forms which are superior as size order to roughness. Within this frequencies area, roughness influence is very little, even insignificant. Adequate spectrum of minimum frequency defines either a maximum or a peak of curves.

-if within the analysed terrain profile there is only one kind of form dimensionaly superior to roughness (only one low frequency oscillation) in the maximum point, periodogram gets quikly lower to a little amplitude value characterised by a high level frequency. In the case are more kinds of superior forms (different low frequency oscillations) in the above mentioned area, there will be either peaks or local maximus at frequencies that correspond them.

-on going, from low amplitude value, periodogram relatively displays non - uniformaly , having low amplitudes, as well. This is high frequencies area or descriptor of roughness contribution to periodogram configuration. Frequency corresponding to its starting point, that makes an utmost change in periodogram, is cutt-off frequency (fc). According to that mentioned in the end of chapter 2.1, this frequency level has been used as a control parameter of filtering process alone by Butterworth filter, through which roughness is separated.

Two exemples of separating roughness parts are displayed in figures 2 and 3. The first profile processed in this way is a plane terrain and the second one a moderate variable terrain. They are succesively conveyed:

-periodogram from input data which make obvious roughness and its frequency level (figures 2b, 3b) ;
-periodograms corresponding to profiles data resulted after filtering is applied (figures 2c, 3c);
-configuration of the two filtered profiles (2d, 3d);
-graphics of roughness values (2e, 3e).

The two profiles are sampled to an interval $\Delta s = 0.5$m between height samples and roughness amplitude component within the 0 - 1.0m range, is considered.

The roughness is determined in different types of applications from the fields how are for exemple: geology, geomorphology, planetary geology or radar remote sensing. In accordance with the nature of the applications its components separations resolutions, can vary at centimetre to metre scale. Taking into account this aspect, Zi(s) height profiles must be sampled to fulfil all imposed accuracy conditions by asked resolution.

The plane coordinates and heights accuracies which can be achieved using photogrammetric methods are dependent on various interrelated factors, but chiefly:
(I) the scale and resolution of the aerial photography;
(II) the flying height at which the photos was taken;
(III) the base / height ratio of the overlapping photos;
(IV) the accuracy of the stereoplotting equipment used for the measurements (Kennie.M.J.T, Petrie.G, 1990).

Out of mentioned factors, for roughness a great importance have, the scale and resolution of the aerial photography. Its separation entail the aerial photos at large scale with a very good resolution.

The aerial photos in the area scale 1: 2000 - 1: 4000, exploited using enlargement factors of 5 or 6, can assure obtaining the components of the 0.15 - 1.0m range, with enough accuracy. But, in the case of the high resolution applications, where the roughness is determinated at centimetric scale, are necessary special photos, at very large scale, obtained with means wich allow taking of the photographic registrations from small altitude. It is enlightening the results obtained using the close - range aerial photos maked with 70mm metric cameras attached to either end of a 6.2m boom, mounted under a helicopter (Wall.S.D, Farr.T.G, Muller.J-P, Lewis.P, Leberl.F.V, 1991). Also, are of maintained concerning to very high resolution determinations, the possibilities offered by close - range photogrammetry, wich can to provide a precision of 1mm (Kirby.P.R, 1991).

Complex numbers involved in the FFT, require twice storage and computational time that real numbers use. For increasing of the data processing efficiency, there is an alternative, the Fast Harley Transform (FHT) (Watson D.F, 1992). This uses only real numbers so is twice as fast while using only one - half the storage.

For technique in this paper presented, must be underlined that an exact correlation between the input data quality and asked resolution is one out of the fundamental factors. Using the height samples having the improper accuracy , can be lead to ambigous situations when the roughness are mixed and confused with measuring errors.

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