Use of geomatic data for monitoring deformation

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To protect big projects from any movements, geodetic control network should be established to monitor the motion of the surrounding area. In this paper points of geodetic network are chosen on the tectonically active area where significant displacements are expected. The method is based on the assumption of the existence of a common signal caused by tectonic disturbances. The common signal is supposed to be present in the geofunctions of the area such as topography, gravity anomaly, magnetic anomaly etc. Harmonic analysis is used to find this common signal. A practical example is used and tested by seismic investigation.

يهتم هذا البحث في كيفية حماية المشاريع الكبيرة من أى تحركات أرضية وذلك بإنشاء شبكه جيوديسية حول منطقة المشروع. حيث يتم اختبار النقط الجيوديسيه عند مناطق التحركات النشطة والتى يتوقع وجود إزاحة مؤثرة عندها. ويعتمد هذا البحث على فرض وجود اشارات قائمة تحدث نتيجة لإضطرابات تكتونيه وهذه الاشارات يفترض حدوثها نتيجة للدوال الجيوديسيه للمنطقة التى تدرس وهى تشمل طبوغرافيه المنطقة وتغيرات الجاذبية وتغيرات المغناطيسية و ... ألخ وكذلك يستخدم التحليل الهرمونى لايجاد هذه الاشارات المنتشره. وقد استخدم لهذا البحث بيانات حقليه وقد اختبرت هذه البيانات كذلك عن طريق التحليل الزلزالى لها. كما تم شرح طريقة معالجة البيانات الجيوديسيه ثنائية الاتجاهات (2D) حيث تعتمد هذه الطريقه على التحليل الاتجاهى والهندسى باستخدام نظرية فورييرر (FFT). وقد اتضح من البحث أن التحليل الهندسى للبيانات يعتمد أساسا على مستوى الضوضاء (noise) التى تظهر فى البيانات وعليه لابد من تنقية هذه البيانات قبل التعامل معها وذلك لتحديد شكل الخطوط التكوينية للبيانات السطحية حيث تدمج هذه الخطوط للمناطق التاكتونية النشطة هذا ويمكن استخدام البيانات المتاحة بدون قياسات حقليه أوجيوفيزيقية اضافية وتعتبر الطريقه المستخدمة فى هذا البحث من الطرق المفيده فى التوصيف المبدئى لاقتراح تحديد أماكن الشبكات الجيوديسيه.

Keywords: Tectonic motion. Fourier analysis. 2D geodata. Seismic area. Faults.

1. Introduction

The security of big industrial projects requires geodetical and geophysical monitoring of the surrounding area, it can be called a micro-scale monitoring, this term is used for area of 10 to 100 km^2.

In the micro-scale monitoring the problems are:

1. which signals should be monitored?,
2. where to do it? , and
3. how to do it?

The answer of the first question is easy from the aspect of geodesy, the vertical and horizontal movements of a geodetic network will be monitored by repeated measurements. Answering the second question seems to be also obvious.

The control network should be located to cover the active and dangerous part of the investigated area where the greatest displacements are expected. Of course if there is no information about the tectonic structure of the surrounding area,
a large geodetic network can be established.

But the increase of the network size is usually irreconcilable with the required precision and with the available funds. So the dimension must be restricted to the necessary and sufficient limits. The question arises; How can the active zone or zones be located without extra field work and measurements?

This question is investigated in this paper and one possible way of the location is demonstrated. This method is based on the uniform treatment of 2D geodata using the tools of Fourier analysis.

The concept of the uniform treatment

The concept of the "Uniform Treatment" is based on the following assumption. If the tectonically active zone has a relatively simple structure, that is:

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1- It is mainly a dip-slip fault.
2- It has a well determined strike direction; and
3- There are no dominant geophysical anomalies in the area which are independent from the fault.

Then the fault generates a common "disturbing signal" in measuring 2D geofunctions like topography, gravity anomaly and magnetic anomaly and horizontal electrical conductivity etc., if the material forming the fault has dominant gravitational, magnetic etc., effects on the area.[1, 2, 6]. In the first step, spectral analysis (The FFT algorithm) can be used to identify the direction of this common " signal " in the different data sets. In the second step a simple 1D (strike direction) or 2D geometrical analysis can be performed on the data sets to locate the trace of the fault.

2.1. Directional analysis of 2D geodata

Since the 2D digital Forward Fourier Transform (FFT) contains information about the direction of its frequency components the dominant directions can be selected by sorting and summing up the power at frequencies into sectors of equal angular subtension according to the azimuth ($\delta_{i,j}$) of frequency components as shown in Fig. 1 [3].

Thus the sectorial (or azimuthal) distribution of Power Spectral Density (PSD) can be determined from the Fourier transform of each digital geofunction and then compared. If the conditions 1,2 and 3 are nearly fulfilled then the distributions must have the same features, that is the same peaks in the PSD because of the significant wavefront caused by the tectonic disturbance. The strike direction of the fault is assumed to be perpendicular to the dominant spectral direction.

By this method one can check the validity of the assumption about the directional features of tectonic structures in the investigated area.

2.2. Geometrical analysis of 2D geodata

The mathematical exact solution of the location problem is based on the classification of surface points of 2D functions. If we consider the sign of the Gaussian curvature at the points of a surface, one can classify them as parabolic, hiperbolic or elliptic points [5]. The sign of the Gaussian curvature is determined by the following formula:

$$LN - M^2 = \frac{\partial^2 z}{\partial x^2}\frac{\partial^2 z}{\partial y^2} - \left[\frac{\partial^2 z}{\partial x\ \partial y}\right]^2 = 0, \qquad (1)$$

where:

L is the second derivative of z with respect to x.

N is the second derivative of z with respect to y.

M is the second derivative of z with respect to x and y.

Here we are interested in the case when this discriminate of the second quadratic form of a surface z = f (x , y) is zero that is the point is parabolic. Strictly speaking there are two types of such points:

a) an inflexion like, and
b) a local extreme like

In the latter case the surface can be replaced by a cylinder of horizontal axis in a sufficiently small surrounding of the point. The two types of parabolic points can be separated by further mathematical analysis or simply viewing the data. The zero Gaussian curvature in the case of point (a) above, locates places where the variation of the data is maximum and it is assumed that these points are nearly over to the strike of the fault. (usually this is also supposed in 1D cross section investigations).

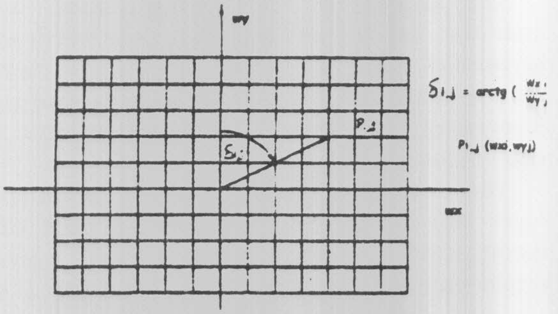

Fig. 1.The azimmuth ($\delta_{i,j}$) of frequency components.

3. Analysis of real data

Four data sets - geodetic and geophysical - were used to locate " structural lines" on the investigated area around a nuclear power plant Fig. 2 and Fig. 3. [These data are collected from the Geodetic and Geophysical Research Institute of the Hungarian Academy of sciences - Sopron - Hungary]

These data are:

a- digital terrain model,
b- magnetic anomalies (Z components),
c- residual Bouguer gravity anomalies, and

d- horizontal electrical conductivity values (S) calculated from telluric measurements (with negative sign).

Because of the discrete form of the analyzed data (64 x 64 data sampled at grid points 100m x 100m) the second derivation was performed by digital convolution. This process was transformed to the frequency domain where it is very simple to do. An FFT algorithm was used to determine the sectorial distribution of Power Spectral Density.

Two dominant directions could be identify in the data sets at 60° and 150° N-E azimuth as shown in Figure 4. The large power at directions of 0° and 90° is caused by the data windowing that is the FFT considers the data to be periodic is not true. It is recommended to highpass filter the data and to window it before the directional analysis by a window function (e.g. 2D parzen window) which has smaller leakage than the simple square window or to use other spectral estimate algorithm which explained in [4].

Before the analysis the data were smoothed by a digital Gaussian smoothing operator Eq. (2) to decrease the effect of noise. The smoothing was performed also by digital convolution.

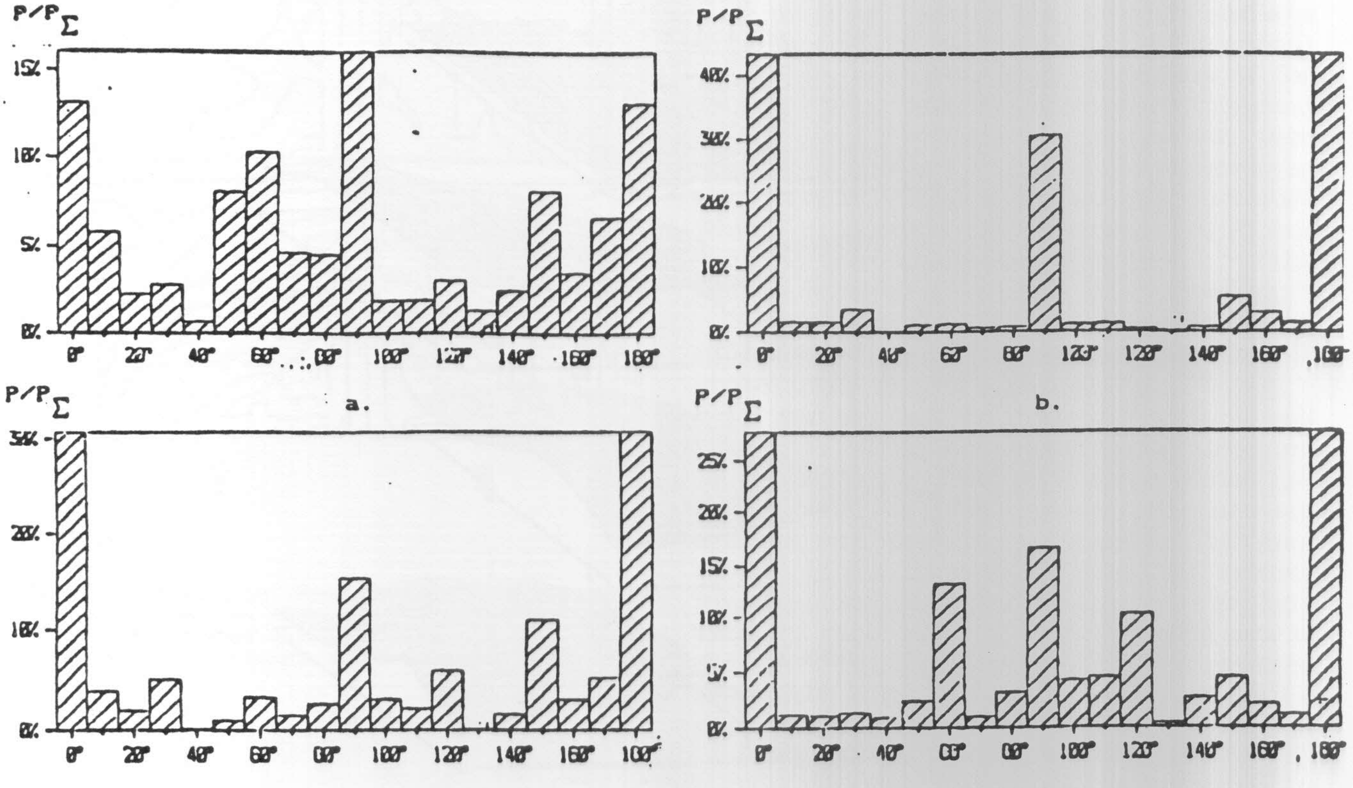

Fig. 2. Sectorial distributions of power spectral density of data sets. a) Digital terrain model, b) Magnetic anomalies (z comp.), c) Bouguer anomalies, and d) Horizontal elec. Conductivity.

$$G_{i,j} = \exp(-A(i^2 + j^2)),$$

where, (2)

$$i, j = -\frac{N}{2}, \ldots, 0, \ldots \frac{N}{2} - 1,$$

and $A = 0.0625 = \text{constant}$

It is necessary to smooth the data sets since the geometrical analysis in the derivation is very sensitive to noise.

Tests with analytical examples show that adding just 1 p.c. white noise to the data points of the examined analytical surface its main structure could not be resolved, although the analysis of noiseless data works perfectly.

The approximation of the derivation difference operators are used in matrix form as follows:

$$\frac{\partial^2 z}{\partial x^2} \cong \begin{bmatrix} 0 & 1 & 0 \\ 0 & -2 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

$$\frac{\partial^2 z}{\partial y^2} \cong \begin{bmatrix} 0 & 0 & 0 \\ 1 & -2 & 1 \\ 0 & 0 & 0 \end{bmatrix} . \qquad (3)$$

$$\frac{\partial z}{\partial x \partial y} \cong \begin{bmatrix} 0 & -1 & 1 \\ 0 & 1 & -1 \\ 0 & 0 & 0 \end{bmatrix}$$

Distortions occurred at the edges of the data sets because of the convolution but it was taken into account in the analysis, as

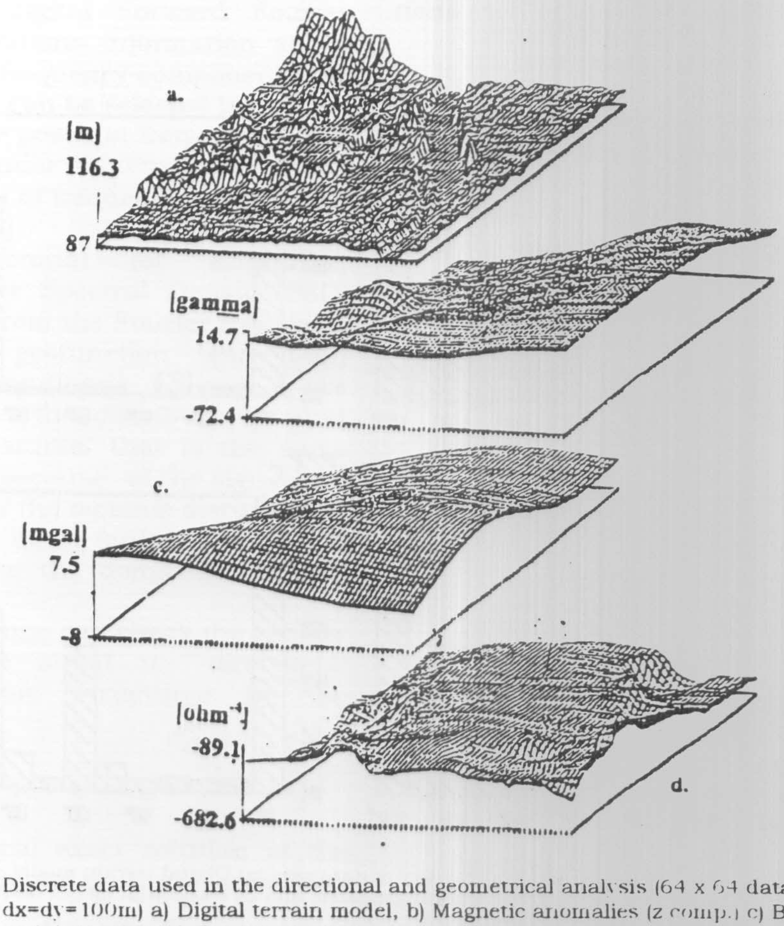

Fig. 3. Discrete data used in the directional and geometrical analysis (64 x 64 data points, dx=dy=100m) a) Digital terrain model, b) Magnetic anomalies (z comp.) c) Bouguer anomalies. and d) Horizontal elec. Conductivity.

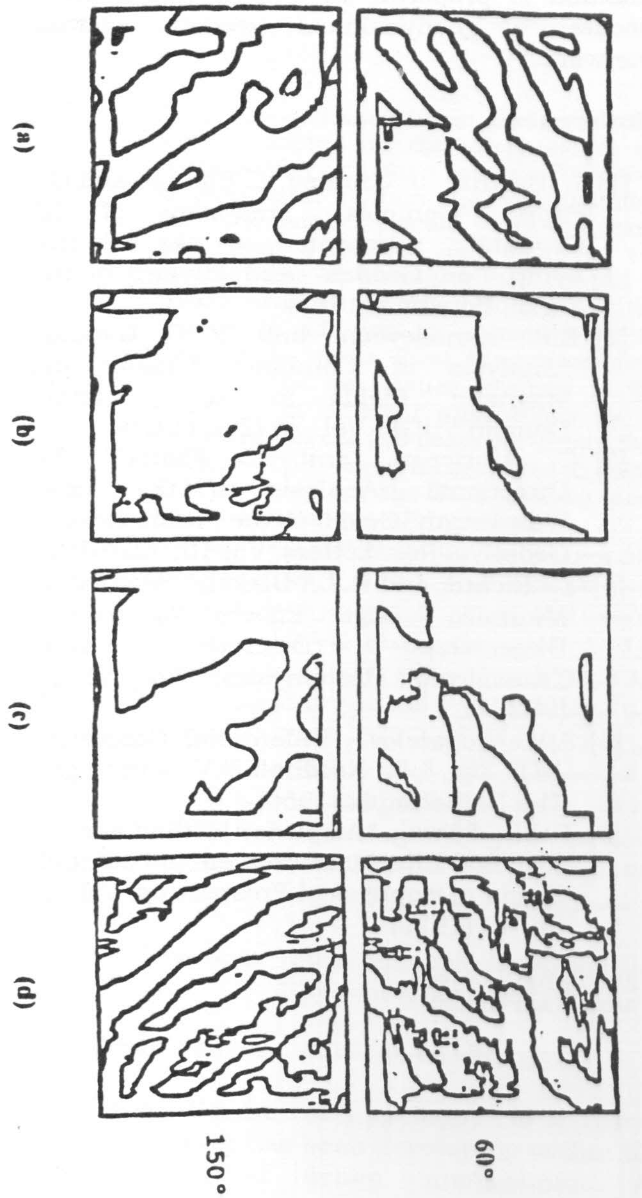

Fig. 4. Structural lines formed by inflexion points of the cross sections of 60° and 150 ° N-E azimuth a) Digital terrain model, b) Magnetic anomalies, c) Bouguer anomalies, and d) Horizontal elec. Conductivity

non-available parts of the data. The results show that after the smoothing process a relatively clear picture of the structure can be given. However, on one hand the residual noise has still considerable effect and on the other hand the real structure of the fault slightly differs from our assumptions. Thus it is tried to adjust further the applied method in the assumptions, namely we extended the 1D cross-section method to a 2D solution in the following sense. Using the results of directional analysis we compute the second derivatives in the dominant directions at every point of the data sets according to the following formula:

$$\frac{\partial^2 z}{\partial \delta^2} = \frac{\partial^2 z}{\partial x^2}\cos^2\delta + 2\frac{\partial^2 z}{\partial x \partial y}\cos\delta\sin\delta + \frac{\partial^2 z}{\partial y^2}\sin^2\delta. \qquad (4)$$

That is we " intersected " the data-surfaces very densely (at every point) in the dominant directions and examined the value of the second derivatives or more exactly second differences (the same matrix operator were used to approximate partial derivatives as in the case of computing Gaussian curvature which exaggerate the phenomena). If this value is zero one get an inflexion point of the section curve.

Comparing the obtained lines formed by inflexion points with the maps of data is shown in Fig. 4.

It can separate the realistic structures and that ones which are caused by the noise and other effects. According to assumptions 1,2, and 3 relatively long and straight lines are selected and then copied together. This final result is not inconsistent with the seismic investigations since the selected lines are very close to each other at the disturbed zone of the corresponding seismic line. The selected structural lines and the seismic sections are depicted in Fig. 5.

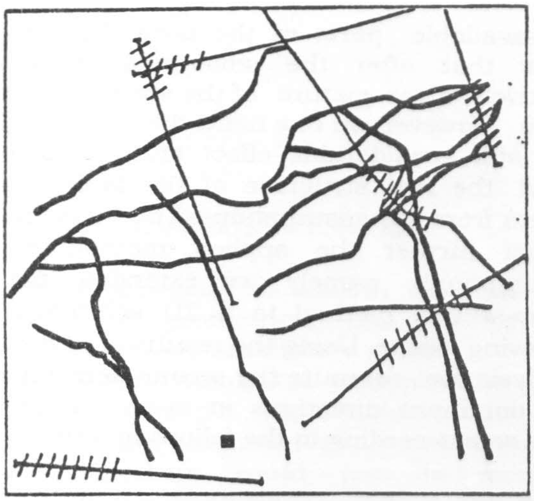

Fig. 5. Seleected structural lines and the seismic cross sections with the disturbed zones marked by hatching.

4. Conclusions

In this paper the method of treating 2D geodata uniformly was investigated. This method based on directional and geometrical analysis using FFT technique. The whole process was tested by analytical and practical example as well. These tests show that the usefulness of the geometrical analysis strongly depends on the level of the noise appearing in the data. So the data sets have to be smoothed before this procedure and rather an 1D approximation of the exact 2D solution should be used to determine the " Structural lines " of data-surfaces. These lines can be connected to the tectonically disturbed zones of the investigated area.

In this analysis it is quite sufficient to use the available field data which does not need extra fieldwork and geophysical measurements. Summarizing the results this method is proposed as a pre investigation to locate a geodynamical geodetic control network.

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