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Metod of Determining the Epicenter of Geomagnetic Disturbance

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***Abstract*—The article deals with the method for estimating the unfavorable living areas for people. The method is based on a distributed registration of the variations of the geomagnetic field and determining the area of their origin. The proposed algorithms are analyzed on the example of irregular geomagnetic pulsations of the Pi-2.**

Keywords—geomagnetic field; irregular geomagnetic pulsations; Pi-2; distributed processing

I. Introduction

During magnetic storms, low-frequency oscillations of the geomagnetic field influence the well-being and health of people in a negative way. For example, during magnetic disturbances the number of heart attacks increases, the reaction of the nervous system, blood pressure and the number of leukocytes in the blood change. In addition, a sudden and sustained change in the geomagnetic field has an impact not only on the physiological functions of the body, but also on his emotional state. Short-period variations of the geomagnetic field cause the greatest danger. The example is the irregular pulsations of type Pi-2, which have an abrupt onset and a prolonged attenuation.

Thus, knowing the direction of the spread of pulsations and the places of their origin it is possible to identify more accurately the areas susceptible to geomagnetic disturbances.

II. Method

The method is suggested for the determination of the parameters of geomagnetic pulsations of the low frequency range and their sources. This method consists in the following stages:

- the registration of the geomagnetic field of the Earth on a distributed network of stations;
- the determination of the parameters of geomagnetic pulsations in a local point;
- the detection and location of the source of irregular geomagnetic waves;
- the determination of the parameters of source of irregular geomagnetic waves.

The registration of the geomagnetic field is carried out on a network of geophysical stations. The network is a number of measurement systems which are far apart from each other.

If you want to evaluate the parameters of irregular geomagnetic waves in a local point, you must carry out pre-processing: the frequency filtering of irregular geomagnetic waves and the assessment of their local parameters.

The detection of the source of irregular geomagnetic waves and its parameters takes place at the central point of the distributed network of stations on the basis of the parameters of geomagnetic waves in the local area.

The locating of the source of geomagnetic waves carries out on the basis of their phase delays on the measuring points.

III. Preprocessing

During pre-processing it is very important to choose the algorithm of the extracting of informative signals. The algorithm must to make the least distortion in the results.

A. Filtration

The algorithm of spectral-temporal filtering (STAN) is used for the pre-selection of geomagnetic pulsations. It does not allow to determinate the qualitative structure of geomagnetic disturbance in real time and thus gives high values of the probability of false detection. To solve this problem, we propose to use filter on the basis of wavelet analysis [1].

For the filtering of geomagnetic pulsations of the low frequency range from analyzing wavelets Haar, Meyer, Daubechies 1 to 10 order, Simleta 1 to 8 order, Koyflety 1 to 5 order the most suitable wavelets are Daubechies 3rd order, 3rd order Simlet, Koyflet 1 order.

The maximum value of the cross-correlation function of the input signal and the resulting signal is 0.63 for the STAN (also the final signal is shifted on 6 seconds in comparative with original signal), and 0.92 for the wavelet filter (the shift was 5 seconds). These results got by comparing the distortions of the algorithm of STAN and wavelet filtering. These distortions are created by the filter in useful signal without noise. According to the results we see that in comparing with the STAN filter the wavelet filter give the best results for conservation form of the original signal and the original signal is delayed on a much shorter time.

B. Mathematical model of Pi-2 pulsations

A new mathematical model of the Pi-2 pulsations should be for a more effective separation of Pi-2 pulsations from the noise. This model must to most accurately match the real irregular geomagnetic pulsations of Pi-2 type. The mathematical description of the Pi-2 pulsations is also necessary for the device of detection and its help to choose the best means of the filtering of Pi-2 signals.

The geomagnetic disturbances such as Pi-2 have a rather complex structure, and the mechanism of their formation and properties are not sufficiently explored.

The pulsation of Pi2 type – is the irregular oscillations of the magnetic field of the Earth with a period of 40-150 s and the amplitude of a few to tens of nT [2]. They are characterized by 5-10 minutes length, the damping oscillations with a sudden sharp start. However, in calm conditions they may have the droplet form with gradually increased amplitude. The spectrum of Pi-2 contains one or more spectral components. The number of spectral components has tendency to increase with increase of magnetic activity. The spectrum of Pi-2 signals may to contain the dominant period, i.e. period that have a maximum intensity in the spectrum. Also Pi-2 pulsation can to have the quite simple structure of spectrum, which consist from only one spectral component, and which is characteristic only for the long-period pulsation (the period ≈ 100 s or more), and which are generated in the time of low geomagnetic activity. The long-range component may be absent in spectrum also.

According to [9], the harmonic structure of spectrum is characteristic mainly for "droplet-image" Pi-2 with continuously increasing amplitude.

On the basis of the above data the mathematical model of the envelope of the Pi-2 signals can be described by the following equation:

$$A(t)=\begin{cases}1-A_{t_1}\cos\left(\dfrac{\pi t}{2t_1}\right), npu\ t\in[0;t_1];\\ A_{t_2/2}\sin\left(\dfrac{\pi(t-t_1)}{t_2-t_1}\right), npu\ t\in(t_1;t_2];\\ 1+A_{t_2}\cos\left(\dfrac{\pi t}{2(t_3-t_2)}+\dfrac{\pi}{2}\right), npu\ t\in(t_2;t_3];\\ 0, npu\ t\notin[0;t_3],\end{cases} \quad (1)$$

where $A(t)$ – the amplitude envelope of the irregular signals of Pi-2 type; A_{t1}, $A_{(t2-t1)/2}$ и A_{t2} – the amplitudes of the corresponding harmonic functions; t_1, t_2 and t_3 – the duration of the individual parts of the envelopes of Pi-2 signals; t – time.

The signal itself can be described by an expression of the form:

$$s(t)=A(t)\cdot\sum_{i}^{N}k_i(t)\cdot\cos(\omega_i t+\varphi), \quad (2)$$

where $s(t)$ – the signal in the time interval t = [0; t_3], t_3 – the signal duration; $A(t)$ – the amplitude envelope; N – the number of spectral components in the pulse; $k_i(t)$ – the factor of the presence of i-th harmonic in the pulsation in the time t, if the harmonic is present then $k_i(t)$ = 1 else $k_i(t)$ is equal to 0; ω_i – the frequency of i-th harmonics; φ - the initial phase.

The presented expressions show that the amplitude envelope is divided into three time parts: t_1 - the time of the rise of the amplitude (leading edge); t_2 – the time of maximum amplitudes; t_3 – the time of the recession of the amplitude (falling edge).

The droplet form of the amplitude envelope is transformed in the amplitude envelope of the form of fading wave train in the case of a sharp increase of amplitude (time t_1 is small compared with the pulse duration of the body), the short duration of time t_2 and a long trailing edge.

970 visually distinct Pi-2 geomagnetic fluctuations were selected to determine of the compliance the developed model of the amplitude envelope of Pi-2 pulsations the amplitude envelope of the real irregular pulsations of the geomagnetic field. Those pulsations were registered on the international network of stations – SAMNET. From a sample of Pi-2 pulsations 494 pulsations belonged the Pi-2 pulsations of the form of drop and 476 belonged the Pi-2 pulsations of the form of the train of damped oscillations. After wavelet filtering, the definition of amplitude envelope and the evaluation of the degree of correlation of selected signals with the mathematical model, we found that 892 Pi-2 signals have a correlation with the mathematical model greater than 0.85.

C. Detection of Pi-2 pulsations

In the existing distributed geophysical systems the used algorithm of the detection of Pi-2 pulsations is based on STAN. This algorithm does not give qualitatively recognizing the Pi-2 from noise. For this reason, as the detector is proposed to use the optimum detector that works on basis the criterion of Baeys.

The interference, that impact on the extracted pulsation and the individual units of measuring channel, is the superposition of the large number of certain elementary random fluctuations, and this multi-dimensional probability of density can be approximated the normal law on the basis of the central limit theorem of probability theory. The white noise will be used as the model of interference, therefore.

The signal with the mixture of white noise enters in the device of detection after passing through a bandpass filter (wavelet filter) and it has the limited spectrum by the bandwidth of the filter. However, the work of the detector will be considered only within the passband of the wavelet filter, within which the spectrum of noise can be considered uniform. Therefore, the white noise can be also accepted as the model of noise.

The criterion of the minimum of the sum of the conditional probabilities of errors is suggested as the criterion of detecting. The method of the Monte Carlo of the increased speed of convergence has used to calculate the probability of false alarm and the threshold of detection. In the time of the determining of the threshold the method of extreme statistics has used for the reducing of the number of experiments and for the reducing of the time of calculation.

The characteristics of the detection of Pi-2 pulsations (Fig. 1) have built with the constant of the probability of false alarm $F = 10^{-3}$ as result. In Fig. 1 the characteristics of the detection of Pi-2 pulsations droplet form have represented from the top, and the characteristics of the detection of the Pi-2 pulsations of the form of the damped train of oscillations have represented from the below. The curves of the number 1 characterize the detector, that is discussed in [3, 4, 5], and at No. 2 - the proposing detector in this paper.

From Fig. 1 the characteristics of detection show that at the input of a receiver the relation of the probability of the correct detection D from the ratio of signal/noise q became more steeper and they are shifted to smaller values of q, compared with the characteristics of detection are presented in [3]. Thus, the value of D approaching to 1 when q is greater than 17 dB (the curve No. 2). In turn, the received characteristics of detection (the curve No. 2) show the achievement of the probability of the correct detection of one at a lower signal/noise ratio in the comparing with the proposed algorithm of detection in [3]. In this case, the probability of the false detection of the signals of the form of attenuation wave train is reduced by about 0.1.

D. Measuring complex

In Fig. 2 the structure of measurement system is suggested for the creating of the proposed algorithms and the organization of a single geographic information-analytical system.

The recorded signals of the geomagnetic field x(i) enter on the input of the bank of wavelet filters after digitizing and amplification. The filtered signal xw (i) of the frequency range of Pi-2 pulsations and the information about the spectral composition: the number of spectral components, the time of their occurrence and loss, the amplitudes of harmonics, etc are on the output of the wavelet filters.

The amplitude envelope of the filtered signal and its extremes mini, maxi are defined next. The threshold rule: min ≥ 10 nT is considered when minimum is calculated.

The fount extremes are served on the block of the formation of the boundaries of the time window. The determination of the boundaries of the time window is a necessary condition for the formation of the reference signal for the block of detectors. The time window is determined by the two neighboring minims of the envelope and by maximum lying between them. At the same the time window should be in the range of 300 to 600 s. If this range of time between two neighboring minims exits from this range, then the additional minimum is involved to the analysis. The additional minimum is found on the next procedure of processing of the filtered sequence.

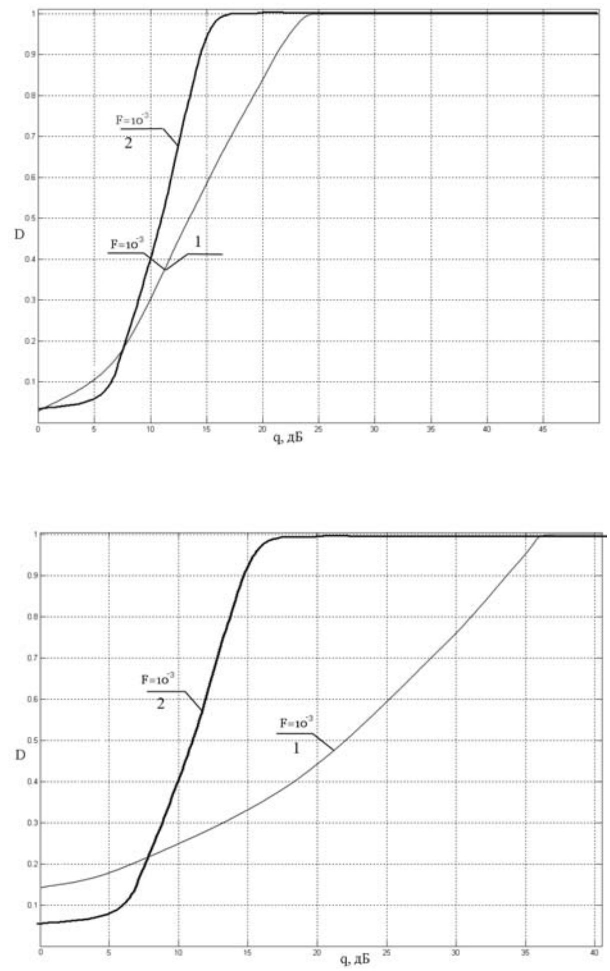

Figure 1. The Characteristics of the detection of Pi-2 signals

The mathematical model of the reference signal is formed for the block of detecting after the defining of envelope, the founding of extremes and time window. The block of detection works on the basis of the criterion of Bayes and the described ratio of likelihood in [5].

If the block of detection decide about the presenting of Pi-2 signal in the considering implementation then all information about it is stored in a database and it is send to the central server for the determining of the spatial parameters of Pi-2 signals and determining of the epicenter of their occurrence.

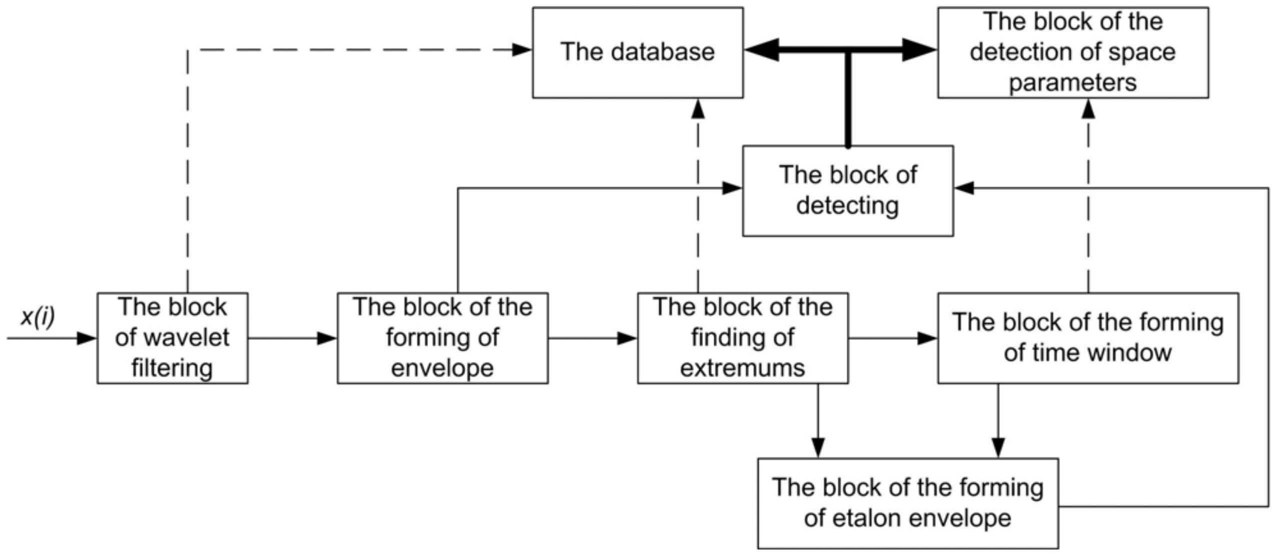

Figure 2. The structure of measurement system

When all the parameters of the probe signal are detected, they are transmitted to the points of monitoring and the points of control, where they are performed for the formation of estimates.

IV. CONCLUSION

Thus, the proposed method of the determining of the epicenter of geomagnetic disturbance is based on the natural signals of the geomagnetic field. A distinctive feature of this method is the ability of the adapting of the reference signal to the input signal on the input of the detector, the using of the distributed network of stations and the block of wavelet filtering.

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