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Second-Order Fractals in the Geospace Researches

L.F. Chernogor[1], O.V. Lazorenko[1], A.A. Onishchenko[2]

[1]V.N. Karazin Kharkiv National University, Kharkiv, Ukraine
[2]Kharkiv National University of Radioelectronics, Kharkiv, Ukraine
oleg.v.lazorenko@karazin.ua

According to the non-linear and the system paradigms, many processes generated in open, non-linear, dynamical systems under influence of a powerful source of energy release are appeared to be short-time, ultra-wideband, non-linear and fractal. The geospace was shown to be a good example of such systems. Many processes caused in geospace by the non-stationary powerful sources of energy release have significant fractal properties. Therefore, the investigations of such properties seems to be actual and interesting.

The purpose of this work is to find so called 'second-order fractals' in the signals and processes registered in geospace during impact of different non-stationary powerful sources of energy release, such as geospace storms, earthquakes, meteoroid falls and other.

The concept of the second-order fractals has been introduced by the authors of this paper in early 2023. Let's consider the main idea of this concept. Well known that to describe a mono-fractal signal, it is necessary to use only one value of the fractal dimension chosen for its analysis. Namely for this reason, such signal was called as 'mono-fractal'. In such case, its fractal dimension D will be constant and not a function of time t, that is D №$D(t)$. But in many practical investigations, being locally mono-fractal (or almost mono-fractal), the real natural signal is appeared to be non-stationary (of course, in sense of fractal properties) and has the fractal dimension $D(t)$, which varies in a time. Strictly speaking, as well as fractal dimension of the signal analyzed has been changed in time, then such signal is a multi-fractal one, and for its investigation, the multi-fractal methods should be used. Nevertheless, we shall consider only the mono-fractal analysis methods used with application of a sliding window in time domain. Such approach was shown to be quietly correct in this case. For a one-dimensional fractal signal $s(t)$, there is only one strict requirement to $D(t)$ function, namely, $1 < D(t) < 2$. If $D(t) = 1$, then a signal is appeared to be non-fractal one. It means that function $D(t)$ can be as smooth as non-differentiable, as deterministic as stochastic. Briefly speaking, it can be a fractal function too. Basing on these reasons, we have proposed a new class of fractals called as 'the second-order fractals'. By the definition, second-order fractal is a fractal, fractal dimension of which is appeared to be a fractal function of time or space variable. A fractal signal with such property is called as second-order fractal signal. Moreover, in such way, the fractals of higher (third, fourth and other) orders can be introduced.

A simple theoretical deterministic model of the second-order fractal signal can be created with application, for example, of well-known non-stationary Weierstrass function, in which the time-dependent Holder exponent ($0 < H(t) < 1$) is present. In turn, to be a fractal function, the Holder exponent $H(t)$ can be modeled with application, for example, the ordinary Weierstrass function. Using such simple models, the fractal and time-frequency properties of the second-order fractal signals were investigated in detail. Moreover, the second-order fractal structures were discovered in temporal variations of the Earth's electromagnetic field detected during the geospace storms, earthquakes and other. The fractal and time-frequency properties of these structures were investigated, the set of corresponding numerical characteristics was estimated.

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Estimation of the Geomagnetic Response to the X-class Solar Flares of September 2017

Y. Luo[1,2], L.F. Chernogor[1], K.P. Garmash[1]

[1]V.N. Karazin Kharkiv National University, Kharkiv, Ukraine
[2]Ghent University, Ghent, Belgium
leonid.f.chernogor@gmail.com

The impact of solar flares on the near-Earth environment has been extensively studied over the years. In this research, we analyzed the geomagnetic response to X-class solar flares that occurred in September 2017, using data obtained from the Low-Frequency Observatory of the