Nonlinear Analysis of Tree Electrical Signals

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Abstract. The change law of Earth’s magnetic field disturbances (Ap index) may be represented by the variation of tree electrical signals. In order to illustrate firstly this regulation, our idea is to discover the internal information or construction of tree electrical signals based on recurrence quantification analysis (RQA) and recurrence plots (RP). By the reconstruction of these time-series signals which can produce relevant vectors, key recursive features (ENTR, DET, RR, and L) were extracted from RP-plot. Consequently, we used the reported values of index Ap from larger to smaller and have found the following recursive signatures regulation: a negative correlation between recurrences and Ap values exists in condition of Ap less than 5. While Ap more than 5, the recurrence values will descend followed by index Ap decreasing. The above results were dig out from one of three camphor trees, and another trees also showed the meaningful specific responses. The conclusions imply that every tree (here three camphor trees under tested) can serve as a cheap and accurate sensor monitoring the geomagnetic disturbances (Ap), for their electrical signals embedded the dynamic terrestrial magnetism. Smart work is necessary for heart healthy care to monitor the impact of geomagnetism information, especially at the level of index Ap up 12.

1. Instruction

Naturally occurring geomagnetic storms (GMS) (0.001 Hz~5 Hz) are induced by solar flares, solar wind, or sunspot activity. The impact of GMSs on biological systems was reported as early as in 1936 (Chizhevsky, 1936) [1]. For a known instance of human health influenced by GMS in tool of Holter ECG, “a 5.9% increase in the 24-hour average of HR (P=0.020) and a 25.2% decrease in HRV (heart rate variability) (P=0.002) were documented on days of high geomagnetic disturbance.”[2]

The geomagnetic disturbances releases less energy than GMS but they affect both cardiovascular disorders and epileptic children/adults [3, 4]. For human beings/trees be all in an embrace of geomagnetic environment, so far this work aims firstly at answering the important questions: Can we find new sensor of Ap? What is the potential connection between geomagnetic disturbance characterized by geomagnetic index Ap (Planetary equivalent range one) (0~150+) and camphor tree electricity?

Researchers believe that geomagnetic energy contains the periodicity, chaos characteristic and the non-stationary states. So far, chaos criterion like recursive analysis was applied in nonlinear system originally by Eckmann (1987), and then gone into the quantitative analysis (1992). With further investigating, they are applied to more fields, like the strain in mechanical system, the medical analysis, the fluctuation on commercial price and geomagnetic analysis [5, 6].

Next we carried out one mini test on the indirect measurement of Ap through the RP and RQA representation.
2. Materials and Methodology

2.1 Camphor Trees

In this research, we chose three camphor trees near the dormitories, which are located in Soochow University campuses (120 degrees, 38 minutes east longitude and 31 degrees, 17 minutes north latitude). The distances between electrode and GND are approximately 50 cm ~ 70 cm (see Fig. 1).

The virtual oscilloscope pen is produced by OWON Company in type VPS021, which is able to catch 5k lengths’ data once a time, with bandwidth of 25 MHz.

Fig. 2 shows the waveforms of wavelet processing. The basic recursive theory is pictured in Fig.3 (step1-5: the process of disassembling fact (5); step6-10: extract every coefficient and multiply)

![Figure 1. The processes of tree electrical signal sampling.](image1)

![Figure 2. Original signals & disassembling waveforms. @ x-axis of 500 dots/div.(s: original signal; \(a_3\): the low-frequency in the third layer of wavelet filter; \(d_3\): the high-frequency in the third layer of wavelet filter)](image2)
2.2 Methodology

Recurrence plot (RP): A recurrence is an operation in time domain that trajectory returns to a location visited before. The recurrence plot depicts the collection of pairs of times where the trajectory is at the same place [7]. Consequently, continues times and phase spaces are necessary to restructure the space vectors by insetting key parameters of different dimensions ($m$) or sampling delay ($t$) [8].

Under the sampling signal lengths of $N$, line $i$ of this reconstruction vector $D$ can be represented as equation (1).

$$x_i = (u_i, u_{i+1}, ..., u_{i+(m-1)t})^T$$

Based on equation (1), we subtract the norm operation of line $i$ with line $j$, in which to construct the reconstruction vector $D$. It is necessary to set a threshold value denoted $X$ to distinguish the elements of vector, for making the vector clearer. As an output, the whole space vector become the 0-1 vector.

By the empirical equation, the threshold value $X$ is equal to 15 percent of standard deviation that is calculated through sampling data [9]. From the visible RP we can only distinguish different “Scotch plaid fabric”, but accuracy values analyses must depend on RQA.

Recurrence quantification analysis (RQA): A RP-plot contains some typical small-scale structures. In sighting them, four recursive features (recurrence, determinism, entropy, length) had been extracted from RP-plots. All of them can illustrate different characteristics of sampling signals under test.

Recurrence ($RR$): This rate is relevant to all recursive points and the square of data length $N^2$, which is shown by equation (2). It can reflect the periodicity of data [10].

$$RR = \frac{1}{N^2} \sum_{i,j=1}^{N} R_{ij}^{m,x}$$

Determinism ($DET$): The determinism is named by the percentage of these segments in all recursive points. This parameter represents the certain information of data [11, 12].

Entropy ($ENTR$): Just like the definition entropy in the thermodynamics system, the entropy here can describe the degree of chaos in data processed[13].

Length ($L$): It describes that the weighted average of all segments in RP plot, showing as equation (3).
\[ L = \sum_{l=l_{\text{min}}}^{N-1} l \cdot p(l) / \sum_{l=l_{\text{min}}}^{N-1} p(l) \]  

(3)

Combining with Fig. 1, Fig. 2 and Fig. 3 we show the key processes of the whole research works, from essential samples choosing to recursive analyses, especially by RQA signatures’ show.

The measurements run at 12 o’clock in Beijing time. The main reason of them is that magnetic signals receive maximum impact from sun activities.

3. Results Analyses and Discussions

We capture data from the east side of the three trunks and to transfer them into the upper computer for storage (Main subject is No.1 tree; and in brief another trees’ analyses are summarized below).

To analyze and dig out the interesting features of these signals have illustrated in Fig. 4, Fig. 5 by RP and Fig. 6, Fig. 7 through RQA in upper computer, respectively.

![Figure 4. RP analyses at 3/25(Ap = 17). @x-axis, y-axis express row and column of reconstructing matrix. Parameters set: m = 4, t = 1.](image1)

![Figure 5. RP analyses at 4/1(Ap = 5). @x-axis, y-axis express row and column of reconstructing matrix. Parameters set: m = 4, t = 1.](image2)
Figure 6. RQA analyses in January. From 2017/12/31 to 2018/1/6. Setting $Ap$ from larger to smaller. Parameters set: $m = 4$; $t = 1$.

3.1. RP Analyses

After analyzing the tree electrical signals by RP, it is shown in Fig. 4 and Fig. 5. We choose two typical results that $Ap = 17$ and $Ap = 5$. The recursive points of Fig. 5 become sparse, while $Ap$ is equal to 5. The numbers of segments and points in the RP-plots increase relatively, especially when parameter $Ap = 17$ (Fig. 4).

When it comes to the distinguishing of situations that the values of index $Ap$ are very high or low ($Ap = 17$ or 3), it will become difficult to compare two sides by naked eye observing. So let us march into RQA.

3.2. RQA Analyses

Basing on RP-plots, we can calculate the recursive features with the recursive points, segments and other parameters in MATLAB 2016a tool. The x-axis of figures (Fig. 4 to Fig.7) is the index $Ap$, which values are to set from larger to smaller. And the y-axes of figures (the same as above) are with different features, such as $ENTR$, $DET$, $RR$, and $L$.

According to the curves in Fig. 6 and Fig. 7, it is very easy to find the regulation between $Ap$ values and recursive features which are extracted from RP-plots (Fig. 4 and Fig. 5).

Consequently, we can establish the relationship between the values of $Ap$ and their recursive features exploring through one of three trees’ electricity (trunk diameter, $D = 107$ cm).

3.3. Discussions

(1) $Ap$ values sharply descent. The data sampling time span must cover the main phase change (reported by Nation).

(2) Geomagnetic direction. We must drive four nails around tree’s trunk in four directions of GM. So that four channels can be captured and selected and recognized per tree.

(3) Filter selection. Through 5 layers wavelet filter, beautiful results curves are gained.

(4) Safety note. Of course, in order to avoid lightning strokes, we not sample data in rain days.
4. Conclusions
Not using the precise magnetic micro sensors and only touching the trees or voices are always our belief for the practical measurements of the phenomenon of geomagnetic disturbances or storms.

This work found firstly there exists the confirming relations between Ap and RP & RQA.

In brief the basic rule is that there was a negative correlation between recursive features and the Ap values (after Ap < 5). Meanwhile, other values of different recursive features descended following Ap decreasing (before Ap > 5).

As for the other two trees (No.2, D = 154 cm; No.3, D = 187 cm), we got specific results:
(1) The regulation between Ap and RQA signatures of No.2 tree: Key point of Ap = 5 becomes a peak value in the RQA induced plots.
(2) The regulation between Ap and RQA signatures of No.3 tree: Four recursive features (DET, ENTR, L, RR) will ascend with the value of Ap descending.

The simple regulation mentioned above will serve as the Medical Science. For instance, according to the recursive features extracted from tree electrical signals[14-16], researchers had estimated the values of Ap. These competitive works will bright primer researches during embracing more trees’ trunks and holding on probes of oscilloscope/new geomagnetic sensors in the world.

Furthermore, in summary our preliminary findings can indicate or reflect the strength or weakness of geomagnetic disturbances.

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