The hybrid time-frequency detection method based on EEMD for balanced tension-type electronic fence

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With the increasing market demand for security, traditional electronic fence products’ performances have been unable to meet people’s needs. As a new circumjacent alarm system, tension-type electronic fence is used widely and become a part of our life. With the enhancement of our safety consciousness, electronic fence which has good safety performance and low false alarm rate will become a new trend. In order to prevent the crime and security precautions. To make full use of electronic fence, we design a type of balanced tension-type electronic fence and the EEMD mode detection method is described in this paper to track the variation characteristics of balanced tension-type fence and alarm recognition in real time. Finally it is proved that this method can accomplish alarm identification reliably and accurately.

Keywords: Balanced tension-type electronic fence, empirical mode decomposition, alarm recognition


Introduction

In nineteenth Century, the electronic fence is mainly used in prisons to prevent criminals escaping, which is mostly made of electrified wire. With the further development of the electronic fence, the technology of it have been widely used in other fields. Electronic fence in the animal husbandry develops quickly, in 1930, Bill invents a high-voltage pulse electronic fence system and put it into the use of animal husbandry which based on the early electronic fence. The pulse energy has a range, it will produce the tingling like an electric shock running through which frightened cattle away from the fence (Zhang Quan and Zhang Zijing, 2012 ). There are many methods that can remove noises used into electronic fence, for example the short-time Fourier transform(STFT) (Zhang Cui, Wang Lixin, 2013), this method covers the shortages of traditional Fourier transform to some extent. But in actual analysis, we can have the optimum effects only using the proper Apodisation functions, which are determined by different signals.

Journal papers (He Cunfu, Li Ying, Wang Xiuyan, Wu Bin, Li Longtao, 2005) mentions the method wavelet transform and Wigner-Ville distribution which are also one of the
popular methods of removing noise, but $WVD_t(t, \omega)$ does not meet nonnegative demands that limit the application of Wigner-Ville distribution; In the final analysis Wavelet transform is still based on Fourier transform, so the selection of Apodisation function and the selection of wavelet base are the important factors that affect the effect.

Huang et al. (Huang NE, Zheng S., Steven R. et al., 1998), a American scientists in 1998 put forward a new analysis method of nonlinear non-stationary data and named it the Hilbert - Huang Transform (HHT). HHT contains two parts: the Empirical Mode Decomposition (EMD) and the Hilbert spectrum analysis.

Empirical mode decomposition is a kind of intuitive, direct, prior, adaptive decomposition method. First, Huang et al. (1998) defined the IMF which should satisfy two conditions: (1) in the whole data set, the number of extrema and the number of zero crossings must either equal or differ at most by one; and (2) at any point, the mean value of the upper envelope and lower envelope is zero. Its decomposition based on a simple assumption that any data are made by a different simple set of natural vibration modal. Each of the linear or nonlinear intrinsic mode represents a simple oscillation, they have the same extreme value point and the number of zero, what is more, they are symmetrical about the local mean. At any point in time, the data may coexist with many different oscillation modes that are stacked together, and these complex and different oscillation modes will constitute the new data.

**The model of balanced tension electronic fence**

**Structural model**

The balanced tension-type electronic is not only an alarm, but also an electromechanical device which can prevent invasion. In compare with several kinds of electronic fence in front of the introduction, this tension electronic fence has better low false alarm rate, and the result that apply to the civil is perfect, and there is no harm to animals and human beings.

**Figure 1. Structure of balanced tension-type electronic fence system**
Balanced tension-type electronic fence consists of three parts: electromechanical components, electronic parts and mechanical components, as shown in Figure 1.

Electromechanical parts are balanced tension detecting devices. Balanced tension detection device adopts balanced tension sensing mechanism and each balanced tension detecting device can simultaneously achieve tension detection of two wire ropes. Under normal condition, balanced tension detection device is in the force equilibrium state. Tension detecting device as a whole is from the wire traction. And the balanced tension detecting device is connected with the tension control board, for detecting the tension of wire rope. The detected analog tension signal is converted into a digital signal and is transmitted to the tension control board, bringing an alarm signal.

Electronic component consists of communications device, tension control board and power controller. Communication device provides data interface to receive and transmit for tension control board. Tension control board with built microprocessors, do differential processing and analysis with received tension digital signal, to determine whether there is an invasion situation; when there is an invasion case, network alarm generates by the communication device.

And mechanical components include wire rope and installation, fixed, supporting and tightening the wire rope devices, such as a lever, force bar, spring etc. The ropes is installed and fixed between the rod, which can be 2, 3 and 4. Each wire rope threads the balanced tension detection devices and both ends of the wire rope are fixed on the rod by the wire rope fixtures. Tension detection device is fixed to the other rod. The spacing between the rod and the rod is not greater than 4m. The spacing between the wire ropes is not more than 200mm.A maximum distance to prevent the zone is not more than 50m.

**Model of alarm recognition**

This paper has introduced the specific structure and working principle of the electronic fence. In practice, we can not regard signals which we received as ideal alarm signal directly.

**Figure 2. Alarm recognition system block diagram**
Hybrid time-frequency detection method based on EEMD for balanced tension-type electronic fence

Balanced tension-type electronic fence adopts a sort of detection method and signal processing method, ensures that changes in the environment will not cause tension alarm threshold values change, and improves the poor environment adaptability of traditional perimeter security detectors, and the disadvantage of easy to false positives. Tension electronic fence, therefore, can have always been loyal to their duties in wind and frost, rain and snow, fog, dust, high temperature, low temperature and other harsh environment, all-weather work is stable and reliable.

First of all, the wire rope on the electronic fence in the area received fluctuate by the invaders, which will produce a series of signals that will be collected by the signal transmission through the communication bus to the total machine. When more than 2 root of wire ropes in electronic fence has signal input, they will be done in the device of switchboard signal screening and identification, confirm if they meet the demands of alarm or not, and then will be sounded the alarm.

**Mechanical model**

In our experiment the data we measured is tension value, not actually amplitude change data of cable, so we have to seek the relations between $\Delta h$ and $F$, and analyze it.

**Figure 3. The picture of simplified mechanical model**

![Figure 3](image)

Take 6 x 7 IWS wire rope as example, its characteristic parameters: wire rope diameter $d = 1.2$ mm, the wire diameter $d' = 0.133$ mm, strand wire lay length is 7.2 mm, inside the wire lay length is 5.4 mm, steel wire of the elastic modulus $E = 180$ GPa, Poisson’s ratio $\mu = 0.3$ (Ma Jun, Ge Shirong, Zhang Dekun, 2009)

**Figure 4. 6x7IWS’s section picture of wire rope model**

![Figure 4](image)
Side strand and rope respectively have the following geometric relationships (Ma Guiying, 2003):

\[
\tan \beta_s = \frac{\rho_4}{2\pi r_4} \tag{1}
\]

\[
\tan \beta_r = \frac{\rho_2^*}{2\pi r_2^*} \tag{2}
\]

\(\beta_s\) and \(\beta_r\) are lateral twist angle and the rope twist angle, \(\rho_2\) and \(\rho_4\) are lay length of side strand and lay length of wire rope, respectively:

\[r_3 = R_3 + R_4\tag{3}\]

\[r_2^* = R_1 + 2R_2 + R_3 + 2R_4\tag{4}\]

The line of curvature and torsion which are defined as:

\[k_2^* = \frac{\cos^2 \beta_r}{r_2^*}, \tau_2^* = \frac{\sin \beta_r \cos \beta_r}{r_2^*} \tag{5}\]
Regard cores and strand as simple and straight, two straight strands respectively for the axial force and moment:

Cores:

\[
\begin{align*}
F_1 &= EA_1'[C_{11}\varepsilon + C_{12}(R_1 + 2R_2)\gamma] \\
M_1 &= E(R_1 + 2R_2)^3[C_{13}\varepsilon + C_{14}(R_1 + 2R_2)\gamma]
\end{align*}
\]  

(6)

Strand:

\[
\begin{align*}
F_2 &= EA_2'[C_{21}\varepsilon + C_{22}(R_3 + 2R_4)\gamma] \\
M_2 &= E(R_3 + 2R_4)^3[C_{23}\varepsilon + C_{24}(R_3 + 2R_4)\gamma]
\end{align*}
\]  

(7)

In derivation process, \(A'_1 = \pi(R_1^2 + m_2r_1^2)\), \(A'_2 = \pi(R_3^2 + m_4r_4^2)\). For a simple straight strand \(C_{11}, C_{12}, C_{13}, C_{14}, C_{21}, C_{22}, C_{23}, C_{24}\) are constant respectively. In the case of \(\varepsilon\) and \(\gamma\), we calculate corresponding \(F\) and \(M\) respectively to obtain these constant. Here simple straight strands of axial force and torque are proportional to \(\varepsilon\) and \(\gamma\).

Total axial force and moment of role in the whole line can be expressed as:

\[
\begin{align*}
F &= F_1^* + F_2^* \\
M &= M_1^* + M_2^*
\end{align*}
\]  

(8)

At the same time, the effect of the total axial force and moment on the whole line \(\varepsilon\) and \(\gamma\) are respectively:

\[
\begin{align*}
F &= EA(C_1\varepsilon + C_2R\gamma) \\
M &= ER^3(C_3 + C_4R\gamma)
\end{align*}
\]  

(9)

E is modulus of elasticity, according to the material conditions of \(E = 180\) GPa, \(u = 0.3\), \(C_1, C_2, C_3, C_4\) is the stiffness constant of wire rope.

\[
\begin{align*}
A &= \pi[R_1^2 + m_2r_2^2 + m_4(R_3^2 + m_4r_4^2)] \\
R &= R_1 + 2R_2 + 2R_3 + 4R_4
\end{align*}
\]  

(10)
Because \( R_1, R_2, R_3, R_4 \) is very small, and the radial deformation is small, so we can approximate thought that: \( R_1 = R_2 = R_3 = R_4, m_2 = m_r = m_4 = 6 \)

Therefore,

\[
A = 49 \pi R_1^2, \quad R_1 = 0.0665\text{mm}
\]

\( \gamma \) is the unit torsion Angle;

So

\[
F = EAC_1 \varepsilon \quad \quad (11)
\]

\[
\varepsilon = \frac{L - L'}{L} \quad \text{(Strain)} \quad (12)
\]

Among them, \( \Delta h \) is the height of the wire rope drop

\[
F = F_i + 49 \pi R_1^2 EC_1 \left( \sqrt{\Delta h^2 + l^2} + \sqrt{\Delta h^2 + (L - l)^2} - L \right) / L + \alpha \Delta T \quad (13)
\]

Among them, \( \alpha \) is temperature coefficient, \( \Delta T \) is temperature variation, considering the actual situation, here we set \( \Delta T \leq 5^\circ C \), \( F_i = 49 \pi R_1^2 EC_1 \varepsilon_1 \) is initial tension, \( C_1 \) is stiffness constant (Velinsky, 1989), \( L \) is rope length, \( l \) is length of endpoint to invasive point.

**Experimental data analysis and processing**

We use experimental electronic fence 6 x 7 IWS, wire rope length of 30 m, initial tension is about 340 N, \( l = 15 \) m.

\[
F = F_i + 49 \pi R_1^2 EC_1 \left[ \frac{3}{2} \left( \sqrt{1 + \frac{4}{9} \Delta h^2} - 1 \right) + \alpha \Delta T \right]
\]

Select a set of data (length 12 s), curve of \( F \) in the right diagram is roughly similar to curve of \( \Delta h \), so when we analyze alarm invasion, we can directly use the \( F \) value instead of \( \Delta h \) value to set high threshold alarm.
Noises can be seen in figure are very disorderly

First Test: 1s, 2s, 4s, 6s momentary force P (Figure 8).

Data acquisition frequency is 50 Hz (0.02s). When momentary force is exerted on wire rope, $\Delta h$ and F value will increase rapidly at the same time. And when the momentary force is removed, curve of $\Delta h$ and F will fluctuate and finally settle out until the elastic potential energy is exhausted. If alarm is caused by sustaining force, $\Delta h$ and F will also follow the changes of sustaining force until sustaining force is removed. We can find start points of oscillation at 50, 100, 200, 300 from IMF5 in the right diagram. They are proved as points of intrude and exactly are consistent with the time we set for first test. It proves our test successes.
Second Test: 1s sustaining force P and then 6s sustaining force P (Figure 8).

Figure 8. Second Test Original Signal and its IMF After EM Decomposition
Oscillatory curve is appeared at point 50 and when it reached the point 300, its amplitude is maximum value. These diagrams all prove set-times of our test are consistent with points which appear oscillatory phenomenon.

Third test: 1s, 3s, 6s, 7s momentary force P (Figure 10).
Conclusion

Balanced tension electronic fence alarm system is a collection of physical protection facilities and balanced tension detection and alarm devices. In the standby detection process, balanced tension detection device of the electronic fence is a two-way force equilibrium state and the overall is not affected by force. Firstly our paper gives the designing scheme of balanced tension-type electronic fence, and puts forward our Alarm identification system solutions, and mechanics mathematical model is established to find the relationship between the parameters of mechanics. What’s more, using the EEMD eliminates noise from original signal, and designing experiment to verify the feasibility and accuracy of the method used in engineering practice.

Reference


Ma Guiying, 2003. Prolonging the service life of domestic wire rope, Shanghai: Shanghai Jiaotong University


