Automatic scaling of F2 layer trace in oblique ionogram based on mathematical morphology and inversion technique

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Abstract

Automatic scaling the ionogram can get the parameters of ionogram, they are vital to detecting ionosphere. In this paper, a new method is proposed to automatically scale F2 layer trace from oblique ionogram based on mathematical morphology and inversion technique, and verified it through actual detecting data and statistical analysis. Results show more than 90% automatic scaling results accord with the manual operation. The method is suitable for oblique ionograms with different high angle waves, and is fast and precise to fitting O-mode echoes in F2 layer without the influence from F1 layer. It could be effectively applied to real-time ionospheric oblique sounding research with good reliability and versatility.

1. Introduction

An ionogram showing the radio wave propagation time delay against operating frequency can be got when using high frequency radio waves to detect the ionosphere. People can extract parameters related to the ionosphere from the ionogram (such as group path, frequency, and so on) which can truly reflect the state of the ionosphere, and the process to extracting the feature parameters is called scaling. Scaling of ionograms initially had to rely on experienced staff for manual operation, this method can provide more accurate results, but was unable to meet the real-time requirements. Therefore, researches drawing automatic scaling the vertical ionogram have done [1-4].

However, automatic scaling algorithm of vertical ionogram cannot be directly applied in the oblique ionogram. Because there are very big differences between the two kind ionograms, concrete embodiment in the F2 layer traces of oblique ionogram consist of low angle wave and high angle wave, and the O-mode echoes in the low angle part overlaps with the X-mode echoes. At present, the public references about oblique ionogram automatic scaling are few. Redding (1996) [5] used a series of steps to complete the oblique ionogram automatic scaling, the steps include filtering noise, refining traces, model fitting and merging traces, this method is only suitable for the ionogram with one high angle wave. Fan Junmei (2009) [6] used morphological operators in digital image processing to identify the E layer trace, the O-mode trace and X-mode trace from F2 layer. Even though some progress has been made in recent years, the reliability and accuracy of the automatic scaling data have remained a challenge.

This paper integrates the morphological operator and the hybrid genetic algorithm into a new method. It is a novel way to automatic scaling F2 layer from oblique ionogram. After the application, results show it is not only suitable for the oblique ionograms with different high angle wave, but also able to fit of F2 layer trace in a fast and accurate way. The automatic scaling method can make full use of the ionogram data, and meet the real-time requirements in practice.

2. The Description of Algorithm

In this paper, the method is discussed from two modules which are the preprocessing ionogram and the trace extraction. Echo signals in the oblique ionogram are mixed with all kinds of noise, shown as Figure 1 (a). In order to

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guarantee F2 layer traces extraction out of unwanted affect, it is necessary to filter out the noise first. So, in the first part, we use Connected Component Analysis (CCA) method to eliminate scatter noise, the method adopts the dilation in morphological operator [7].

The core part of automatic scaling is the trace extraction, which directly affects the automatic scaling results. There are some E(Es) layer traces in the ionogram after preprocessing, the existence of them will seriously affect the F2 layer traces extraction. So we should remove the E (Es) layer traces. In order to extract the trace features of F2 layer, it is necessary to go on a thinning operation [8] after expanding. Getting some points $P_i(f_i, p_i)$(i=1,2,3,...) as the original input data of inversion algorithm in the thinning trace, P_i is the corresponding observed group path at the detection frequency f_i. Then put the selected points into the inversion algorithm, we can get the fitting trace of F2 layer O-mode trace. The common inversion algorithms include iteration algorithm [9], genetic algorithm [10] and simulated annealing algorithm [11], etc. This paper adopts a new inversion algorithm [12] - hybrid genetic algorithm, the algorithm is better than genetic algorithm and simulated annealing algorithm on optimization ability and stability. From the fitting trace, the height of F2 layer (*h'F2*) and the maximum usable frequency of F2 layer (*F2MUF*) can be get, as show in figure 1(f).

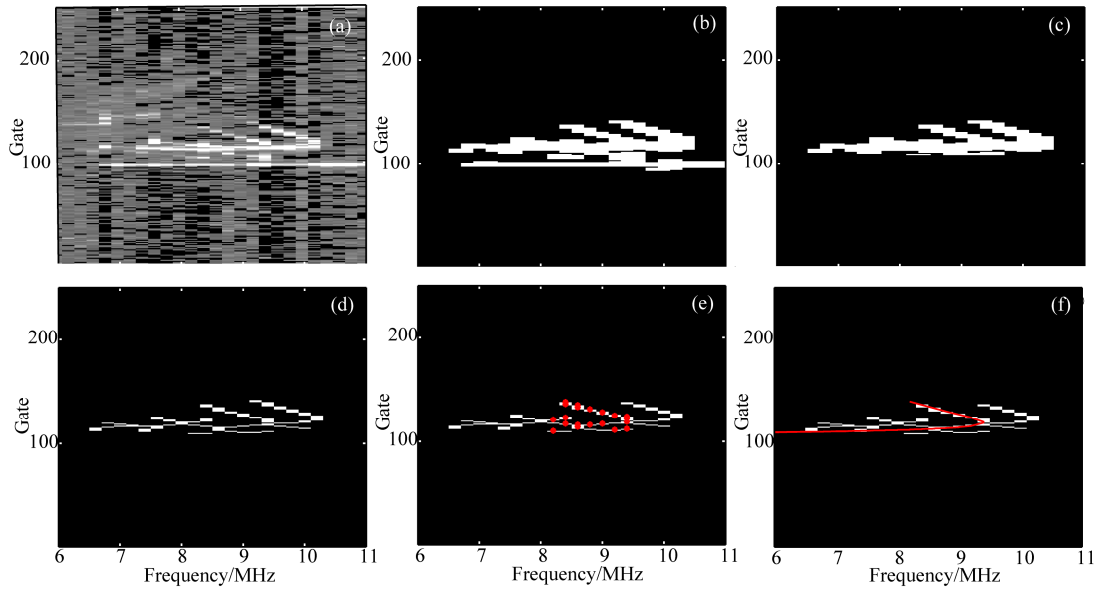

Figure 1. The whole process of automatic scaling. (a) The ionogram before preprocessing;(b)Removing noise;(c) Eliminating E(Es) layer;(d)Thinning trace;(e) Selecting points(the red "*");(f)Fitting trace(the red line)

3. The Application of Automatic Scaling Algorithm

In order to verify the automatic scaling method described in this paper, we use the method to analyze actual oblique ionogram data which is obtained in the Ionogram Laboratory of Wuhan University on August 24 to 26, 2010, and the results are compared with manual operation. The oblique detection devices work in scanning frequency mode from 6MHz to 30MHz. The pace of scanning frequency is 0.2 MHz, and the distance resolution ratio is 12.5km. There are 41ionograms suitable for automatic scaling. Figure 2 presents the fitting results of three different high angle waves state ionograms by using the automatic scaling method described above.

In this paper, we take manual operation results as reference value. The range of the allowable error is ±3Δ (Δ is the resolution of ionogram) higher than the ±5Δ of International Union of Radio Science(URSI)[4]. Figure 3(a)and(c), show the automatic scaling results of the all ionograms. The curves of *F2MUF* and *h'F2* changed with the time from up to down. The horizontal axis is the world time.

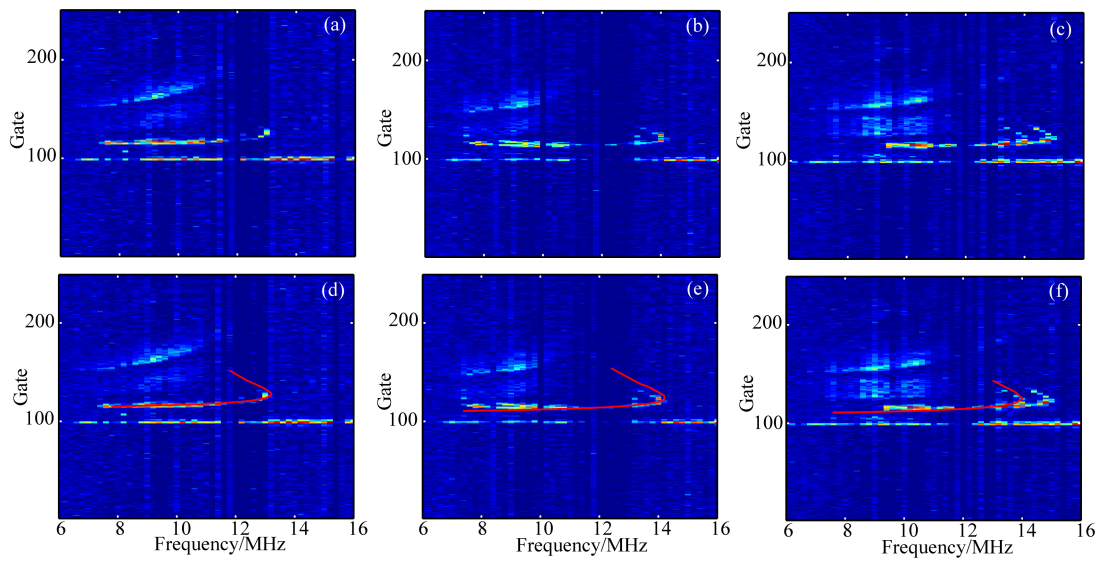

Figure 2. The fitting results of three different high angle waves state ionograms. (a, d) No high angle wave; (b, e) One high angle wave; (c ,f) Two high angle waves; The red lines in (d, e, f) are the fitting trace of O-mode echoes.

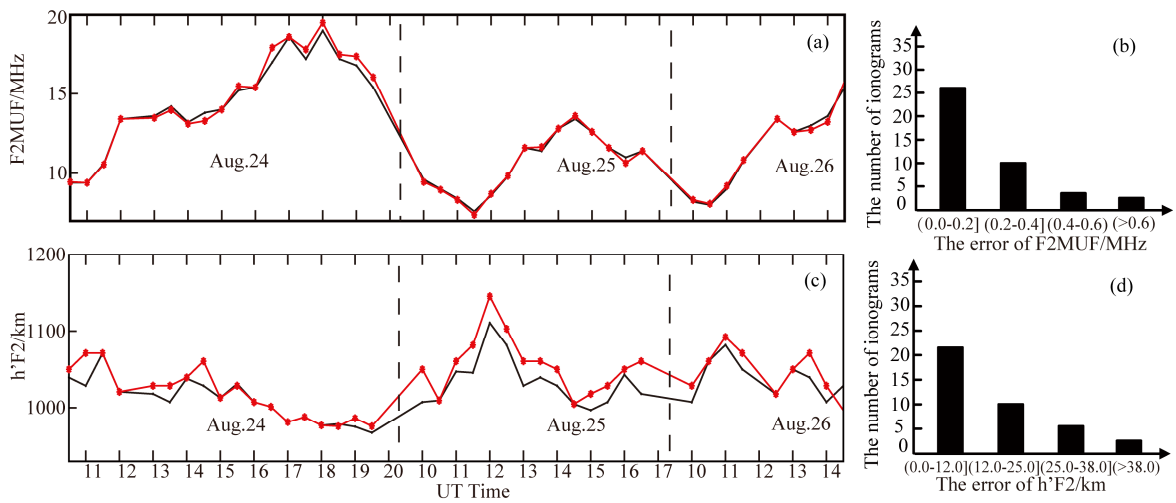

Figure 3. The results of automatic scaling and manual operation (a, c). The red cross is reference value while the black dot is the automatic scaling results. The statistical results of the error of *F2MUF* (b) and *h'F2*(d)

The correlation coefficient (ρ) of *F2MUF* between automatic scaling and reference value is 0.997, and the ρ of *h'F2* is 0.910, they are all nearly 1; the mean-square error (σ) of *F2MUF* and *h'F2* are 0.243MHz, 20.239km, better than the defined acceptable range. Consequently, the automatic scaling data are close to the reference values and their variation trends are almost the same. Figure 3(b)and(d) show the statistical results of automatic scaling data. The *F2MUF* is 95.1% within acceptable range while *h'F2* is 92.7% within acceptable range. Therefore, the acceptable results of automatic scaling are more than 90%.

4. Conclusion

This paper presents a novel method to realize the automatic scaling of oblique ionogram. The data on August 24 to 26, 2010 show that the method can extract ionogram parameters with high accuracy and reliability, and suitable for different high angle waves state ionograms. It does not need the polarization information from detection device, and works less than 30 second. This method has a good adaptability and development prospects.

5. Acknowledgments

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6. References

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