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Signal Processing Techniques in Ionosphere Sounding and Trace Extraction from Ionograms

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Abstract—**The ionosphere plays an important role in high-frequency radio communication. An ionogram, as an effective way to get useful information of ionosphere, should be analyzed correctly and effectively. Unfortunately, the ionograms are generally distorted by background noise and strong signals interferences from other transmitters. In this paper, two techniques are proposed to obtain high-quality ionograms by reducing those interferences. The proposed techniques contain radio interference mitigation and modified mean filtering. These techniques have been well proved by data from ionosonde and perfect result could be seen from the comparison between the processed data and the unprocessed data. After getting the clearer ionograms, an algorithm is proposed for extracting main traces from the ionograms which is based on image recognition. Also, the performance of this algorithm is tested by data from ionosonde and the result is perfectly well. The test data were obtained from the ionosonde operating at Dulan. The proposed algorithms in this paper should be useful for further analysis of ionograms.**

Keywords-ionograms; radio interference mitigation; modified mean filtering; extracting; ionosonde

I. INTRODUCTION

With the development of communication, it is inevitable that receive signals from a high-frequency radar will be contaminate with other radio emissions which are considered as radio interference. Besides this, there are kinds of other noises, such as Gauss noise and salt and pepper noise, in the process of transmitting and receiving signals. These interferences mentioned above make it difficult to analyze an ionogram correctly and effectively. Therefore, methods to eliminate or reduce these interferences while preserving the ionospheric characterizes in the ionograms are desirable.

In previous researches, ionogams enhancement was based on phase coded pulse compression, coherent Doppler integration [1], different typed of windows [2], size-contrast filter [3], median filtering and edge detection [4]. In this paper, two techniques are proposed to obtain high-quality ionograms, which contain radio interference mitigation and modified mean filtering.

However, it is not enough for obtaining a clear ionogram, the various parameters related to the characteristics of the ionosphere in an ionogram are more important. Much work has been performed to scale the ionograms and ionospheric characteristics were given as output [5],[6],[7]. In this paper, a method is proposed for extracting main traces from the ionograms which is based on image recognition. This work will be useful for further scaling work of the ionograms.

In section 2, two algorithms have been proposed to eliminate the different kinds of interferences. The two methods have been tested with data from ionosonde operating at Dulan on 12th July and the results are also given in section2. Section3 describe an algorithm based on image recognition, including dilation, erosion and thinning and give the results of this algorithm. These techniques have been well proved by data from ionosonde and perfect results could be seen from the comparison between the processed data and the unprocessed data.

II. PROPOSED ALGORITHMS OF ELIMINATING INTERFERENCES IN IONOGRAMS

To eliminate the interferences in received signals of ionosonde, the paper describe two methods, radio interference mitigation and modified mean filtering separately.

A. Radio Interference Mitigation

The radio interference mitigation proposed here is different from the previous algorithms developed by Bibl [8]. This algorithm is applied after pulse compression and coherent integration, which is based on the characteristics of the radio interferences. The interferences, typically strong signals from other transmitters, have the same property which will bring disturbances covering the whole range at a fixed frequency, while echoes from the ionosphere do not have this property. The echoes from the ionosphere which have larger amplitudes are limited in a specific range rather than the whole range of detection. Therefore, if we calculate the average value of all received signals amplitudes at each frequency, the interferences will be stand out because the received signals which influenced by the interferences will have a larger average value. Due to this character, we can remove this type of interference according to the following steps:

1) Calculate the average of all the signals amplitudes covering all frequencies (including the noise amplitude) in the ionogram and define it as A, multiplied it by an experience coefficient k_1 and then define the result $k_1 \bullet A$ as a threshold which will be used to filter the radio interference.

2) Calculate the average of the signals amplitudes at each frequency and define the series as a set a. The set is composed by the values $\{a_1, a_2, a_3, \ldots a_i, \ldots\}$, where a_i represents the average of the sum of all the amplitudes at a fix frequency f_i and i represents the sequence number of the frequency.

3) Compare each member of set a with the threshold $k_1 \bullet \overline{A}$, if $a_i > k \bullet A$, it is presumed that the signals at frequency f_i are contaminated by the radio interferences and we define the frequency of interference as f_I.

4) After f_I defined, it is simply to subtract the average a_i from each received signals at f_i and the value below zero is set to zero.

Now, the radio interferences have been eliminated by the method above. In the next section, the paper will introduce a modified mean filter to remove other noises.

B. Modified Mean Filter

Besides the interferences mentioned above, there are kinds of noises emerge in the process of transmitting and receiving signals, generally, impulse noise and Gaussian noise are the two main noise types. After removing the radio interferences, the next step is to eliminate the disturbance of other noises. In this paper, an easy but effective method is proposed. This method which based on the differences between noises and echoes from ionosphere uses a modified mean filter. First of all, a concept should be admitted is that the echoes from ionosphere is much larger than the noises. Typically in an ionogram, most points, considered as background, have no value which means there were no received signals at the corresponding points. Based on these principles, it is easy to distinguish virtual echoes from noises and the background. Thus, the procedure of this method is described as follow:

1) Distinguish the received signals with the background and count the numbers of the signals n (points with values).
2) Calculate the sum of signals S and the average S/n.
3) Multiplied the average S/n by an experience coefficient k_2, and get the result $k_2 \bullet S/n$ which is considered as a threshold to eliminate the noises.
4) Subtract the threshold from each signal and the value below zero is set to zero.

C. Experimental Results and Comparison

After proposing the methods, we test these algorithms with data from ionosonde operating at Dulan on 12th, July. The ionosonde implemented the swept-frequency detection from 1 to 10MHz with 20 kHz step to detect the ionosphere. The bandwidth of transmit signal is 30 kHz and the result can be seen in Fig. 1 and Fig. 2.

From the result, it is obviously that the performance of these algorithms is efficacy. Fig. 1 and Fig. 2 demonstrate the differences between the ionogram without and with the algorithm mentioned above. In Fig. 2, the effect of these algorithms is obvious: (1) the interferences have been subtracted from the ionogram, (2) the improvement of SNR is clearly visible.

Figure1. Ionogram before reducing interferences. The ionogram is obtained from field experiment with ionosonde operating at Dulan on 12th, July.

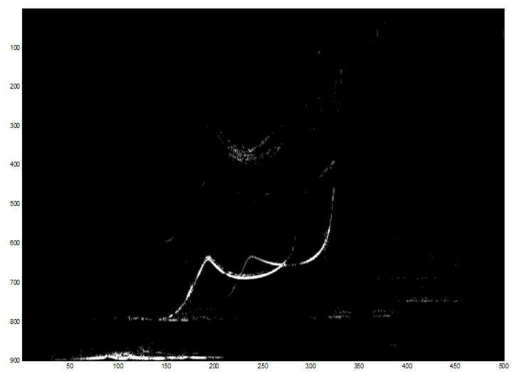

Figure2. Ionogram after reducing interferences. The ionogram is obtained from field experiment with ionosonde operating at Dulan on 12th, July.

III. PROPOSED ALGORITHM TO EXTRACT MAIN TRACES FROM THE IONOGRAMS

A. Main Processes of This Algorithm

After getting a clear ionogram, next step is to extract the trace of each layer. In this paper, an algorithm is proposed to achieve this goal. In the algorithm described here, an ionogram is regarded as a two-dimensional image, where frequency, range, and signal amplitude are input parameters. The main processing steps are as follows:

1) Converting the ionogram into a binary image.
2) Dilating the image. This operation is to gradually enlarge the boundaries of regions of foreground pixels and thus some holes in ionogram, especially the F trace, could be connected again. Here the algorithm of dilation is omitted.
3) Labeling the connected components in the image, and then the image is divided to groups which composed of pixels connected with each other. Once all groups determined, each pixel is labeled with a number according to the component it was assigned to. Here we just take F layer trace for example: the following step is to calculate the center and area of each group to elect the main F trace. The principle of election is based on the F trace's generally height and its bigger area.
4) Eroding the image. This operation is opposite to dilation, which is to erode away the boundaries of regions of foreground pixels.
5) Thinning the image, which is used to get the skeleton of the image, is the last step of this process. Due to the limitation of the article's length, the details of this algorithm are omitted. The skeleton extracted here is what we want, the F trace.

B. Experimental Results and Comparison

The performance of the algorithm above has been tested with data from ionosonde operating at Dulan, which also be used in paragraph 2.2. Experimental results of each step in this algorithm can be seen from Fig. 3 to Fig. 8.

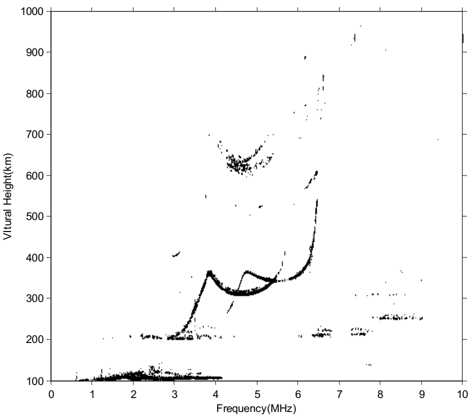

Figure3. Binary image of the original ionogram.

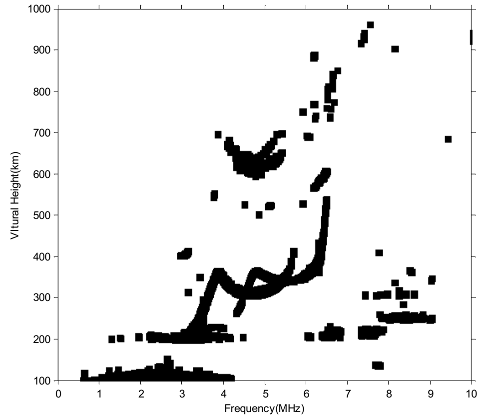

Figure4. Ionogram after dilating.

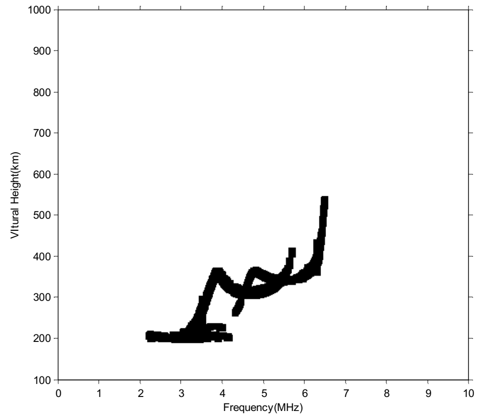

Figure5. The main F trace eleted from the dilating ionogram.

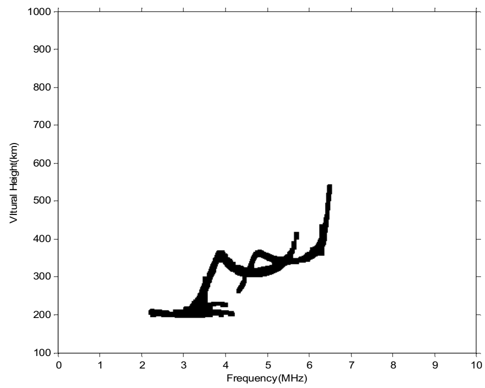

Figure6. Ionogram after eroding.

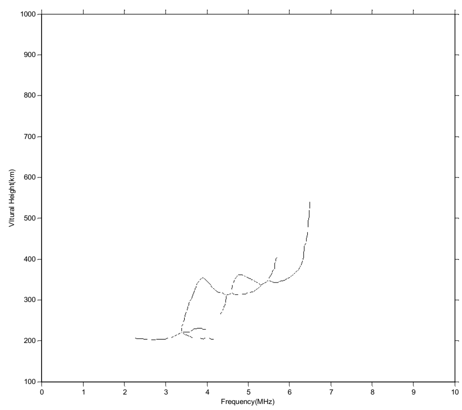

Figure7. Ionogram after thining.

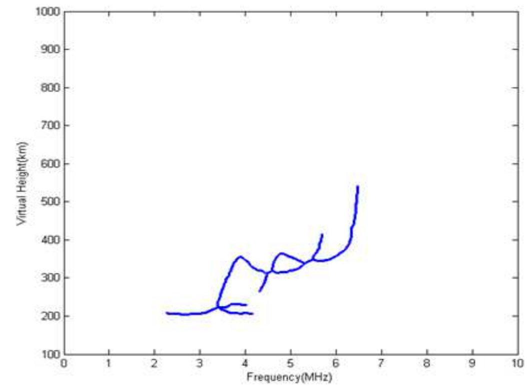

Figure8. The main F trace extracted from ionogram.

From the ultimate results (Fig.7 and Fig.8), it is clear to see that F trace has been extracted from the original ionogram. Obviously, each step is functional and the outcome is perfect well. Further analysis, such as scaling critical parameters from ionograms automatically, will be based on this method.

IV. CONCLUSION

Radio interference and other kinds of noises are significant factors influencing ionosondes. In this paper, we have described two basic techniques, including radio interference mitigation and modified mean filter, to eliminate noises from ionograms. The algorithms have been proved with data collected from experimental field and the results of the experiments are encouraging. Apart from that, this paper proposes a method to extract the F trace. This method has succeeded in extracting the main trace from ionograms, however it needs more training which will be discussed in the future.

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