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ON THE PROBLEM OF AUTOMATIC PROCESSING OF BACKSCATTER AND VERTICAL-INCIDENCE IONOGRAMS

Ivan A. Galkin
Institute of Solar-Terrestrial Physics, P.O.Box 4026, Irkutsk, 664033 Russia

INTRODUCTION

Now-casting and short-term forecasting of HF radio circuits requires a real-time input of current ionospheric data. A studios effort is being made to automate data capture and to exclude human operator from the procedure of ionospheric data processing and interpreting. An effective solution to these problems may be found within the scope of ground backscatter plus vertical-incidence (VI) sounding technique, as it imposes no requirement of real-time data transfer via communication lines being capable of sensing ionospheric paths thousands kilometers away from a sounder site.

The paper addresses principles of automatic scaling of ionograms designed for a system [1] of now-casting radio circuits up to 9000 km long within a region equipped with a single ionosonde performing backscatter and VI sounding of the ionosphere.

GENERAL PRINCIPLES OF DATA PROCESSING

The system of now-casting circuits uses an FMCW ionosonde [2] recording an ionogram as a gray-scale raster picture of curves representing variation of echo delay vs. frequency of the ionospheric path under examination. To extract necessary information from an ionogram, a two-stage procedure is performed: (1) extracting curves from ionogram and (2) interpreting curves and evaluating parameters. The first stage requires a pattern recognition algorithm; a linguistic analysis should be applied at the second stage.

EXTRACTING CURVES FROM IONOGRAMS

TERMINOLOGY. Ionospheric echo occupies a certain interval of delay on a scan; a time-of-arrival (TOA) can be evaluated for each echo. On the plane of ionogram ionospheric echoes of the same propagation mode form a "trace", whereas points of TOA form a "track".

GENERAL APPROACH. Two approaches to extracting curves may be mentioned. Within the first approach an evaluation of TOA is performed for each echo and a tracking routine is applied to a point pattern thus produced. In the second approach TOAs are evaluated after all traces are extracted by a segmenting algorithm applied to a whole picture. In this paper both backscatter and VI ionograms are processed following the first approach.

ECHO PROCESSING. A rather conventional scheme of echo processing is applied including adaptive thresholding, spike removal, splitting overlapped echoes, TOA evaluating and spatial filtering of TOA sequences ('m- out of -n' validating criteria). An adaptive technique of splitting overlapped echoes was established to avoid false detections of TOA point in case of spread echo, which analyses sufficiency of a valley between two peaks to split them onto separate echoes.

CURVE TRACKING: BACKSCATTER IONOGRAMS. A tracking algorithm was developed to extract curves from a backscatter point pattern. The algorithm is based on a turning histogram technique (THT) [3] developed for processing bubble chamber data; fast algorithmic realization [4] of THT was implemented. THT is based on the principle of fitting a narrow rectangle mask to a track line by altering its location. A quasi-linear configuration of main backscatter tracks allowed application of THT to the whole plane of ionogram. When the mask positions a track, the number of points inside will show a local maximum. A second-order stringing routine is then used for exact tracking a curve within the mask thus found, supplied with a simple track initiation procedure. Finally a smoothing spline is applied to the track points.

CURVE TRACKING: VERTICAL-INCIDENCE IONOGRAMS. A local tracking algorithm [5] was developed to extract curves from a VI point pattern. The same principle of fitting a mask was used, but a considerable modification was made to the over-all scheme of altering, combining and chaining masks, as the fitting procedure can be applied only to a slice of a VI ionogram.

For a single TOA point, the left side of a mask is fixed on the point, different inclination angles are probed, and the best variants of mask orientation are stored. On a single slice, all TOA points of first several frequencies of the slice are tested resulting in a set of best mask orientations. Then a procedure of combining masks is performed to avoid mask intersections, basing on a robust principle of a higher rank for mask with a greater number of points inside of it. Each track element thus extracted is partly left in the whole set of TOA points with a corresponding marker to provide chaining the next element of the track.

INTERPRETING VERTICAL-INCIDENCE CURVES

The complexity of automatic interpreting VI curves is increased in our case by requirement that the algorithm should not rely on information about polarization, angle-of-arrival and Doppler shift of echoes, which can be obtained only by the advanced sounding of ionosphere.

An approach of linguistic image analysis were chosen for the interpreting, which implies searching base elements, presence or absence of which enables the algorithm to make an identifying decision. Thus, base elements play the role of starting points for interpretation, and the final result of procedure immediately depends on immunity of base element searching algorithms and the order of searching itself to noise and interference, variety of possible curve configurations, unexpected situations, and errors occurred on previous stages of processing.

The following order of base element search [6] (Fig. 1) is selected:

1. E-REGION DATA. Noise-protective algorithm [7] is used to determine critical frequency, foE, half-thickness of the parabolic profile, ymE, and height of the layer peak, zmE.

2. CENTER OF F-LAYER. The notion and searching technique of the F-layer center was introduced in [7].

3. Es-LINE. Es-line is the line of tracks to the right from E-layer critical frequency, foE, and below F-layer center.

4,5. TRACKS OF BOTH POLARIZATION COMPONENTS CLOSE TO CRITICAL FREQUENCIES OF F2 (or F)-LAYER. At the next step, the algorithm approaches the picture from higher frequencies.

The same idea was independently suggested in [8]. Choosing this way of action is worthy of note, as typically a technique of "reading" ionogram from left to right is proposed, so that F2 data is reached in the last place. In our case F1 data, which was causing a lot of hardships to automating, is approached from both sides, consolidating its position by the base elements already found.

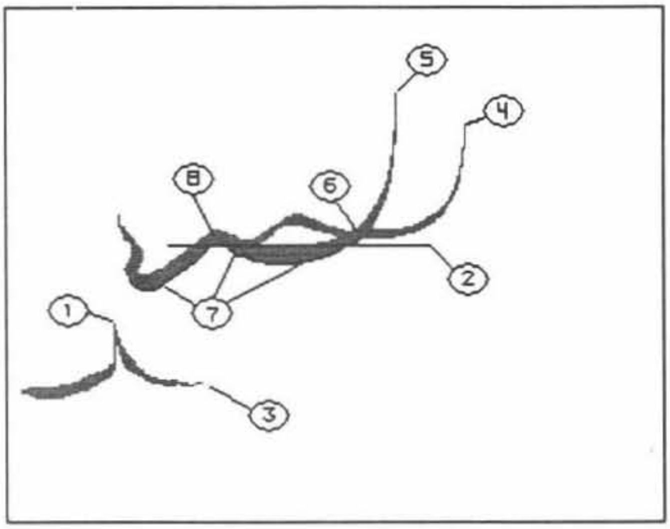

Fig. 1. Sequence of base element search.

The algorithm of searching tracks close to F2 cusps is quite different from that suggested in [8]. The first base element is the very right (outermost) track element with positive inclination (its searching procedure is carefully surrounded by additional checks, which are to increase noise immunity). The algorithm [7] for precise critical frequency evaluating is then used. Choosing the outermost part of the tracks nearby the F2 critical frequency of X-component as a base element appeared to be good in a number of respects: as a rule, it is even better seen than the critical frequency of the O-component (in spite of greater absorption), more frequently appear to be in better noise conditions and, most importantly, have no intersection with the other component on its rising part.

Searching the other component track is probably the most complicated part of the interpreting algorithm. Different situations are taken into account, including loss of rising part of tracks, TIDs effect, etc.

The difference of critical frequency values determined is checked whether it corresponds to 1/2 gyrofrequency. If there is no correspondence, it means that one or the other value was determined incorrectly. In this case, an attempt is made to identify which value of the two is incorrect by determining the quality of fitting. If this procedure is successful, the incorrect curve is changed to the correct one, shifted by 1/2 gyrofrequency and fitted by height.

This self-control technique has imparted rather high quality of processing adequacy to the algorithm. Preliminary operation test showed that 95% of critical frequency values (324 samples, mid-latitude daytime ionograms, moderately disturbed ionosphere) have errors 0.1 MHz and less, only 1% of scaled values having errors 0.3 MHz and greater. This test also showed the analysis scheme to have certain immunity to weak and moderate stratifications in F2 layer close to critical frequencies.

6. POINT OF DIFFERENT POLARIZATION TRACKS INTERSECTION IN F2(F)-LAYER. The curves found are traced down to their intersection point.

7. O-LINE. To search O-line, an area between critical frequency of E-layer, foE, and component intersection point is allocated. O-line is formed by track points having maximum amplitude on each sounding frequency. It is expected to be the line of O-component echoes (which have greater energy, as a rule). However, O-component has greater energy not in every case, so each fact of switching to another track is specially analyzed for "height-step" effect.

8. KINKS AND FRACTURES OF THE O-LINE. Existence of F1 will be expressed as kink or fracture of O-line. Stratifications, TIDs, errors in intersection areas, etc. may cause several extrema of the O-line; the one will be treated as F1, for which ratio foF1/foE is the closest to the value of 1.47, selected by experience.

Preliminary results of F1 determination algorithm showed that in 18% of cases (122 ionograms concerning F1 problems, mid-latitude ionosphere, moderately disturbed conditions) extremum corresponding to F1 critical frequency was extracted incorrectly. A major part of mistakes was the result of false F1 detection as a kink due to tracking algorithm errors caused by "bobbing" of TOA points in F-spread conditions. The most effective way to avoid these errors is solving the problem of more careful TOA determination. The next problem with foF1 is the loss of F1 due to deficient sensitivity to slight changes of inclination in periods of F1 appearing or disappearing, when its existence is questionable.

INTERPRETING BACKSCATTER CURVES

Currently a simple task is formulated to extract 1-hop F-layer backscatter curve, which is typically the main on an ionogram. This data is sufficient to obtain, for instance, a variation of MUF vs. (ground) range [9] or a spatial gradient of electron density profile [10] in the direction of sounding, or to update long-term prediction of HF propagation on a circuit. So the main backscatter curve found on an ionogram is simply treated as a 1-hop F-layer curve. A study of applicability of this principle shows that it works in major cases. Procedure of interpreting a more complicated ionogram can be done using a long-term prediction of backscatter behavior to find the curve among extracted tracks.

CONCLUSION

Approaches to an automatic processing of backscatter and VI ionograms for a system performing remote real-time now-casting of HF circuits were outlined. A further investigations are required in order to find what could be done to improve the system.

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