AUTOMATED MODE SEPARATION IN OBLIQUE IONOGRAMS

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AIM

To separate the *o*-mode and *x*-mode traces as a key step in autoscaling oblique ionograms.

MOTIVATION

Many sounders do not provide polarization information, particularly in the case of oblique sounding, where it is difficult to obtain this information from hardware. The polarization information is *vital* when performing trace extraction.

APPROACH

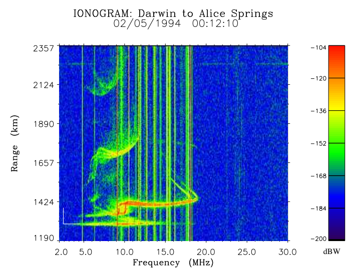
Two approaches have been tried.

(i) Deconvolution: which attempts to separate the two modes by assuming they are the result of convolution of a single mode.

(ii) Image processing (IP) mode separation: A combination of several image-processing techniques are used to separate

RAW IONOGRAM

An oblique ionogram recorded in support of the Jindalee over-the-horizon radar program at Alice Springs [1].



The two polarization modes appear as two superimposed copies of the F-layer traces.

To first order the polarization modes can be approximated by a linear shift in frequency [2].

In general this linear shift does not hold, but it is a good approximation near the *nose* region of the trace.

The shift may vary with group range.

DECONVOLUTION: METHOD

The two traces are assumed to be produced by a 1D-convolution (in the horizontal direction) of a single trace with a bi-modal kernel. Hence the problem of separating the *o*- and *x*-mode traces is then one of *deconvolution*.

- A convolution may be written $\mathbf{y} = H\mathbf{x} + \mathbf{e}$, where $\mathbf{x}$ is the signal to be estimated, y is the measured or convolved signal and e is white Gaussian noise. Least squares estimation of $\mathbf{x}$ gives $\mathbf{x} = (H^T H)^{-1} H^T \mathbf{y}$, but the calculation of the inverse can be numerically unstable.

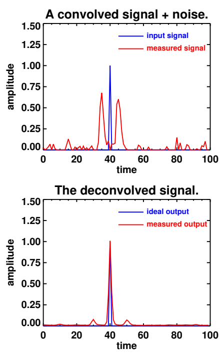
- The LMS algorithm [3] estimates $\mathbf{x}$ recursively, taking the *(k+1)*th estimate of the signal, $\mathbf{x}_{k+1}$, to be

$$\mathbf{x}_{k+1} = \mathbf{x}_k + \mu H^T(\mathbf{y} - H\mathbf{x}_k),$$

  where m is a parameter chosen to make the solution stable. Variations of LMS can incorporate the fact that $\mathbf{x}$ is positive.

- The convolution kernel is not know in advance so a range of kernels are tried, and only the best result kept.

- The convolution kernel may vary with group range so each row of the ionogram is deconvolved separately.



DECONVOLUTION: PREPROCESSING

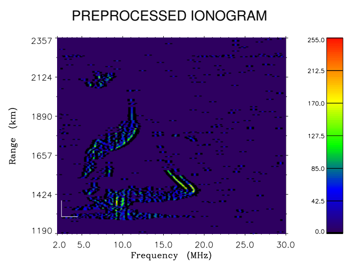
The ionogram contains noise, overlapping parts of traces and traces which are not part of the F-layer. These can be partially removed through preprocessing.

The method used is to:

(i) Remove RFI by independent adaptive thresholding within each frequency band.

(ii) Enhance vertical ridges by convolving the rows of the ionogram twice with an edge enhancement kernel. The kernel chosen was the derivative of a truncated Gaussian distribution (standard deviation 0.1 Mhz), which has the simultaneous effect of smoothing the resultant ridge-enhanced ionogram.

(iii) Threshold the ridge-enhanced image at the average of the maximum and minimum pixel intensities in the ionogram.



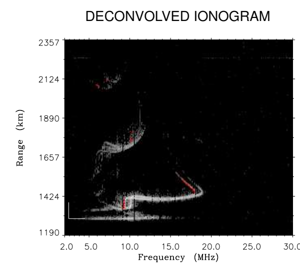
DECONVOLUTION: RESULT

The deconvolved ionogram has been thresholded, first in intensity, and then by the area of connected regions. The remaining points are shown to the right, overlaid on an ionogram with the RFI removed.

- In general the deconvolution has worked well, though other parts of the ionogram, for instance the second-hop trace, may produce spurious points, or interfere with the F2-layer trace points.

- The downfall of this method is the time taken. An average case can take more than 20 minutes to run, on a DEC Alpha.

- Even with a significantly faster algorithm, this time would be prohibitive for real-time application, though with future technical improvements it may become practical.



IP MODE SEPARATION: PREPROCESSING

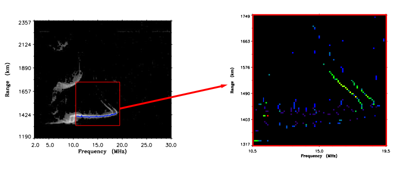
An alternative approach is to perform mode separation as part of trace extraction. This works well as the major motivation for mode separation is to facilitate trace extraction. Thus the mode separation can occur where it is both necessary and sensible to do it.

- The method used is based upon image-processing techniques.

- The trace extraction algorithm finds a set of possible lower-ray traces. The algorithm then focuses on each lower-ray trace approximation selecting a region around the trace, called the region of focus (ROF).

- The ROF is preprocessed, by removing unwanted points due to the:
  (i) lower ray,
  (ii) width of traces.

- Points due to the width of the trace are removed using a gray-scale skeletonisation algorithm [4].



IP MODE SEPARATION: ALGORITHM

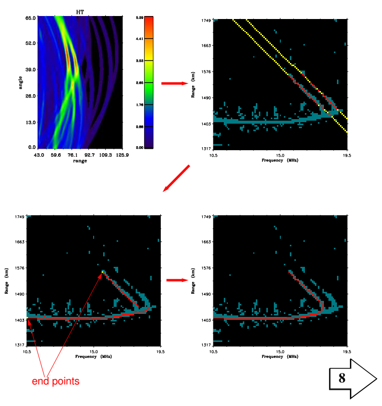
- The preprocessed ROF is Hough transformed [5], which transforms straight lines into peaks in a Hough space.

- The upper-ray traces, modelled as two parallel straight lines appear in the Hough space as a pair of peaks.

- The location of the two peaks in the Hough space gives a straight line approximation for the upper-ray traces, and the separation between the two traces.

- The end points of the lower-ray and upper-ray approximations for the *o*-mode F2-layer trace are found.

- Dijkstra's algorithm [6] is then used to find a least cost path between the two end points. The cost used is a negative exponential of the pixel brightness.



CONCLUSION

- Although deconvolution successfullly removes the x/o-mode ambiguity from an ionogram, it is too slow to be currently useful in real-time.

- An alternative method refered to as IP mode separation was explained here. The method is integral to trace extraction.

- IP mode extraction has been sucessfully used on ionograms recorded in support of the Jindalee over-the-horizon radar [7].

- IP mode extraction is fast, and robust to RFI, spread F, overlapping traces, and travelling ionospheric disturbances.

- The method is quite generic and has been applied successfully to other sets of ionograms (with different transmitter and receiver locations and different frequency, range and power resolutions).

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