TRACE EXTRACTION FROM OBLIQUE IONOGRAMS

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AIM

To extract the traces from an oblique ionogram and select the F2-layer o-mode trace for input to an inversion algorithm.

MOTIVATION

To automate ionogram trace extraction, as part of a real-time propagation advice algorithm for HF radar and communications applications.

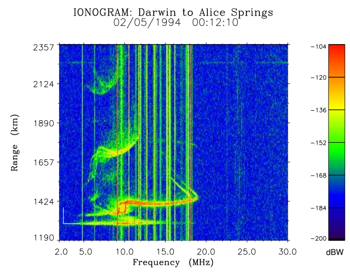
The F2-layer is concentrated upon becasuse it is the most important layer for HF propagation while the E- and F1-layers can be well modelled.

APPROACH

Apply emerging image-processing and computer-vision techniques.

RAW IONOGRAM

Oblique ionograms are recorded at Alice Springs as part of the Jindalee over-the-horizon radar project [1].

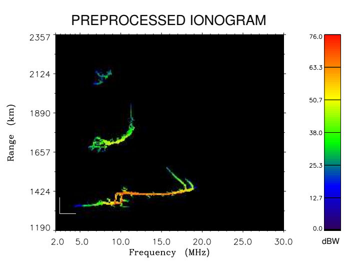


Inherent Difficulties

- **Radio frequency interference** (RFI) causes the vertical lines in the ionogram.
- **Spread F** can cause the F-layer trace to be spread over both range and frequency.
- **Blanketing** of the F-layer by sporadic E may remove parts of, or the whole F-layer trace.
- **Overlapping traces** as a result of o- and x-mode traces and multi-mode traces may make separation of traces difficult.
- **Travelling ionospheric disturbances** may distort the shape of the trace significantly.

IONOGRAM PREPROCESSING

The ionogram is preprocessed to remove RFI and other forms of noise.

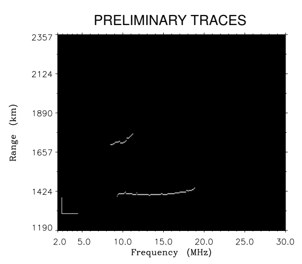


Preprocessing Steps

- **RFI removal:** RFI is removed through the adaptive thresholding of each frequency band.
- **E-layer trace removal:** The E-layer trace and sporadic E are removed through a horizontal profile of the ionogram.
- **Smoothing:** The ionogram is smoothed using the closure operator from mathematical morphology [2].
- **Ridge enhancement:** The ridges in the ionogram are enhanced using the morphological top-hat transformation.
- **Area-based thresholding:** The connected regions on the ionogram are adaptively thresholded on the

PRELIMINARY TRACE EXTRACTION

A set of preliminary traces representing the low-ray traces are found.



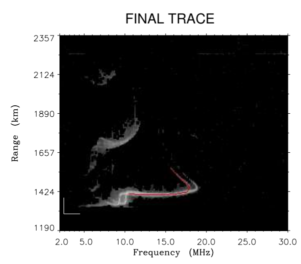
Preliminary Trace Extraction

- **Starting points:** Find a set of bright, well-distributed starting points.
- **Tracking:** Track horizontally from the starting points using a Kalman filter [3].
- **Remove redundant tracks:** Several tracks may overlap, so the redundant tracks are removed.
- **Break the tracks in segments:** Based on the shape of the tracks break them into segments.
- **Classify the tracks:** Classify the track segments using
  - (i) position,
  - (ii) length.

Discard the segments with a low probability of being part of the F2-layer.

FINAL TRACE EXTRACTION

The preliminary traces representing the low-ray traces are further investigated. The upper ray-traces are found and the final trace is found and classified.



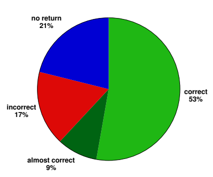
Final Trace Extraction

- **Find Regions of Focus:** The region of focus is a rectangle around the initial trace approximation.
- **Find Upper rays:** Use the Hough transform [4] to find the upper-ray traces which are modelled as a pair of parallel straight lines.
- **Find the final traces:** Find a least cost path between the ends of the upper-ray trace approximation, and the lower-ray trace approximation, using Dijkstra's algorithm [5]. The cost function used is a negative exponential of the power returned in a given frequency/range bin.
- **Classify the traces:** If more than one preliminary trace was investigated the final traces must be classified, to select the F2 *o*-mode trace.

QUALITATIVE PERFORMANCE ANALYSIS

The algorithm was applied to a set of 100 ionograms recorded during days ??? to ??? of 1995, and the results classified into one of four categories:

- **Correct** - the extracted trace was as good as (or better than) one extracted by a human operator. Note that the correct traces were chosen quite stringently.
- **Almost correct** - the trace had some small defect in shape that did not correspond to the actual trace, but would probably still be acceptable.
- **Incorrect** - the trace had some major defect which would make it useless for further processing.
- **No return** - the algorithm classified the ionogram as too hard to extract a trace from and so no trace was returned.



In ~15% of the ionograms an experienced scaler would have trouble returning a *trace*.

The reliability = (proportion correct/ proportion with a return) = 78%

QUANTITATIVE PERFORMANCE ANALYSIS

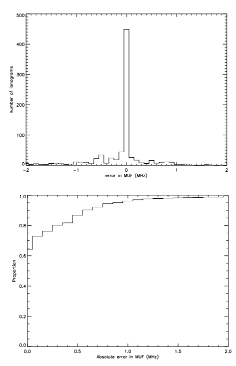
Quantitative assesment of the algorithm was made by comparing the autoscaled value of foF2 with manually scaled foF2, for ~1000 ionograms recorded during days 168 to 197 of 1995. This has been used for performance assesment elsewhere [5,6], and gives a good measure of the accuracy of a trace.

The value of foF2 measured manually was assigned an error range and the measured error was taken to be the distance of the estimated value from this range.

The algorithm returned a trace for approximately 70% of the ionograms considered, and the relative frequency of errors, and the cumulative frequency of errors in the returned traces are displayed in the histograms to the right.

The latter histogram shows that 73% of traces were found within 0.1 MHz of the estimated range of foF2 for the F2-layer trace.

Less than 10% of traces were in error by more than 0.5 MHz.



CONCLUSION

- An algorithm has been developed for the extraction of the F2-layer o-mode trace from oblique ionograms.
- The algorithm has been designed to be robust to RFI, spread F, overlapping traces, and travelling ionospheric disturbances.
- The algorithm has been adapted successfully to other sounding systems.
- The algorithm is fast.
- The algorithm is modular and amenable to modification.

REFERENCES

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[5] E.W. Dijkstra, *Numerische Mathematik* 18, pp. 269-271, 1959.

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