On The Blind Detection of FRBs through Spatial Fourier Transforms

Marwan Alkhweldi[1], Richard Prestage[2], Ryan Lynch[2], and Natalia A. Schmid[1]
(1) Lane Department of Computer Science and Electrical Engineering,
West Virginia University, Morgantown, WV, USA
(2) National Radio Astronomy Observatory, Green Bank, WV, USA

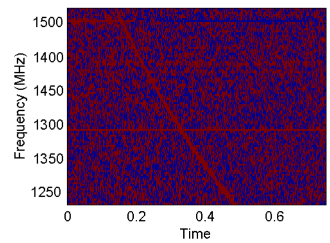
***Abstract*— This paper presents two methods for the blind detection of Fast Radio Bursts (FRBs). The methods are applied to filter bank data (also known as a spectrogram or (t,f) plane). The methods are designed to detect FRB signatures in the 1D Fourier Transforms (1DFFT) and in Spatial Fourier Transforms (2DFFT) of the (t,f) data. The signature of a FRB in the 2DFFT plane is a line with a slope between zero and 90^o (but not zero or 90^o) in the range of low spatial frequencies. In the sum of magnitudes of the 1DFFT of each frequency channel in the (t,f) plane, the signature of a FRB appears as a relatively strong and approximately Gaussian bell shaped pulse centered around zero frequency. The detection methods are different approaches to detect these signatures. To detect the line in the 2DFFT, we use a Hough transform. To detect the presence of an FRB signature in the 1DFFT approach, we evaluate the total power in the data and compare it to a decision threshold. The paper presents a performance analysis of each detection method.**

I. INTRODUCTION

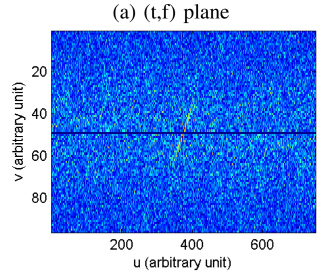
FRBs are broad spectrum sources that emit their radio signals over a wide bandwidth. The observed FRB signals are dispersed and relatively weak compared to many discovered pulsars and other celestial emissions. Furthermore, the observed FRB signals are usually corrupted by noise and some radio frequency interference (RFI). Detecting FRBs is a challenging task and there are only a few FRBs currently known. This work summarizes two efficient approaches to blind detection of FRBs and presents an analysis of their performance.

II. 2DFFT METHOD

The 2DFFT detection method is based on the application of the Spatial Fourier Transform (2DFFT) to (t,f) data followed by the Radon transform and a search for the maximum magnitude [2]. A dispersed signal present in a spectrogram is described by a continuous function relating a time delay t of a signal and an inverse quadratic function of the corresponding channel frequency f, with the unknown Dispersion Measure (DM) value as a scale factor. The function can be roughly approximated by a linear function. An example of a FRB is shown in Fig.1[1]. Fig.2 is an example of a case when no FRB is present. The Spatial Fourier Transform of a linear function with a slope different from zero or 90 degrees is another linear function with a nonzero slope, which is

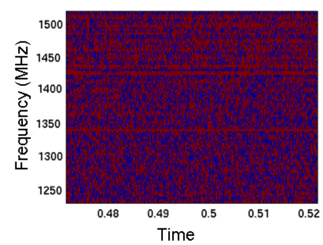


(a) (t,f) plane

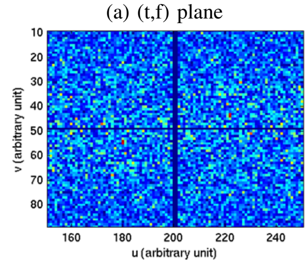


(b) 2DFFT space

Fig. 1: Lorimer Burst.



(a) (t,f) plane



(b) 2DFFT space

Fig. 2: No FRB.

directly related to the slope of the original line. The signal duration (pulse width) of the original line in (t,f) space defines the length of the transformed line in 2DFFT space. The orientation of the transformed line is a function of the DM value. RFI is characterized by a zero DM value and may be broadband at a single time (bursty) or persistent at a single frequency. Such interference shows up along vertical and horizontal lines in 2DFFT space, and so may

MA would like to acknowledge the support of the National Radio Astronomy Observatory Research Experience for Graduates Program. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

be nulled. A previous comparison of the conventional dedispersion/pulse detection algorithm and its blind counterpart based on 2DFFT has shown that the conventional algorithm displays much higher sensitivity (also known as a detection SNR) [3]. The results of our tests have demonstrated a different outcome. By focusing on the region of low spatial frequencies in 2DFFT space, we can reach a significant improvement in detection SNR compared to the earlier work.

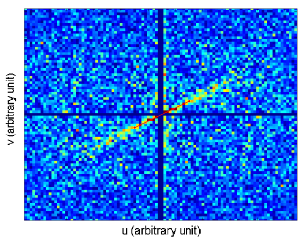


Fig. 3: 2DFFT of Lorimer burst with highlighted detected line.

The Receiver Operation Characteristic curve (ROC) is used to demonstrate the performance of this detection method. The ROC is a curve which presents the true detection rate versus the false alarm rate of a detection method. Due to the limited amount of FRB data available, observations of the pulsar J0922+0638 were used to generate the ROC curve shown in Fig.4. Using the known J0922+0638 timing solution, the location of individual pulses in the J0922+0638 filter bank file were used as a ground truth for testing the performance of the detection method. The J0922+0638 filter bank data was divided into small time windows of data. With the priori knowledge of which of the time windows had pulses in them and which had not, the detection method was applied to all of the windows, to find the true detection rate and the false alarm rate. A true detection event is an event when the detection method detects a pulse in a filter bank data window known to contain a pulse. A false alarm event is the event when the detection method detects a pulse in a window which does not in fact contain a pulse. The ROC curve shows the relation between the rate of true detections to the rate of false alarms as the decision threshold varies.

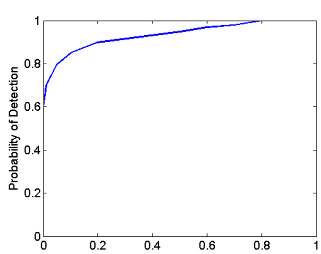


Fig. 4: ROC for the detection method based on 2DFFT.

III. 1DFFT METHOD

This detection method uses a 2DFFT to remove RFI, but then simply inverts the special frequency representation back to the (t,f) space representation. It then sums the magnitudes of the Fourier Transform applied separately to each frequency channel in the (t,f) data, along the time dimension. The total energy of the data is evaluated and compared to the estimated energy of data containing no signal (noise only). If the energy exceeds a predefined positive threshold, the method claims signal detection. An example of an FRB and its 1DFFT are shown in Fig.5. Fig.6 is an example of a case where no FRB is observed. The ROC generated by applying

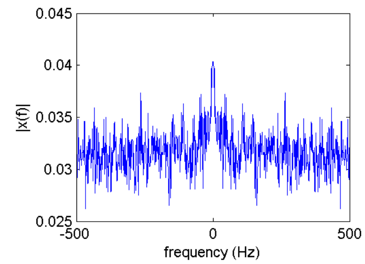


Fig. 5: Sum of magnitudes of 1DFFT for Lorimer Burst.

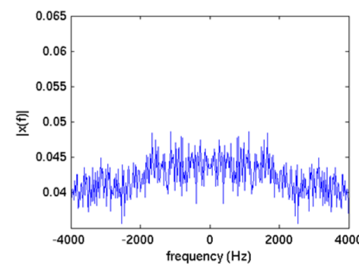


Fig. 6: Sum of magnitudes of 1DFFT for No FRB.

this detection method to the J0922+0638 pulsar data is shown in Fig.7. The decision threshold for this approach is the total energy of the data around zero frequency.

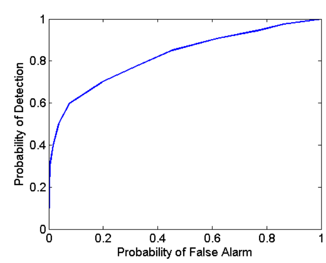


Fig. 7: ROC for the detection method based on 1DFFT.

IV. CONCLUSIONS

Two efficient algorithms for FRB detection have been developed and their performance has been analyzed. After multiple trials the performance of the methods are displayed as ROC curves. These results demonstrate that at a cost of a relatively low false alarm rate (about 10%), the correct detection rate reaches 90%.

REFERENCES

[1] D. R. Lorimer, M. Bailes, M. A. McLaughlin, and D. J. Narkevic et al, *A Bright Millisecond Radio Burst of Extragalactic Origin*, Science Magazine (Science) 318 (5851): 777–780, 2010.
[2] M. Petrou, and C. Petrou, Image Processing: The Fundamentals. John Wiley and sons, 2010.
[3] D. Ait-Allal, R. Weber, C. Dumez-Viou, I. Cognard, and G. Theureau, *Blind detection of giant pulses: GPU implementation*, Comptes Rendus Physique, Volume 13, 2012.