National Centre for Radio Astrophysics

Semester Project Report - 15 December 2021

A real-time beamformer data monitoring tool for the GMRT

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Introduction

The project served as a general introduction to radio astronomy, particularly pulsar astronomy and various observational aspects. To that end, reasonable amount of time was spent on covering the basics and understanding the nature of the data by playing around with GMRT data of a few pulsars. Emphasis was also put on looking at the observational tool for pulsars, called the GMRT Pulsar Tool (gptool) and gaining the technical familiarity needed to work on the beamformer monitoring tool. Below is a summary of the foundational activities done before the actual project work-

- Writing my own C programs for (i) folding the pulsar data, (ii) extracting individual pulses, (iii) calculating on and off-pulse energies in individual pulses (fig 1) and (iv) performing cross-correlation between 2 pulses.
- Using these programs, some time was spent understanding the on and off-pulse energies, the probability distribution they follow (fig 2) and how the distribution changes based on how the energies are calculated.
- The gptool plays a central role in the beamformer monitoring tool, described later in this report. So effort was put on understanding the tool, how it performs real-time RFI filtering, dedispersion, folding and exploring its many features.
- In the data for PSR B1642-03, it was noticed that half-cycle away from the main on-pulse there was another fainter emission appearing at a period much larger than the pulsar period. One explanation of this inter-pulse emission is free precession of this pulsar, but further investigation is needed.
- Learning to use shared memories in both python and C as a method for inter-process communication (IPC). Additionally, I gained familiarity with the data acquisition and beamformer systems at GMRT.

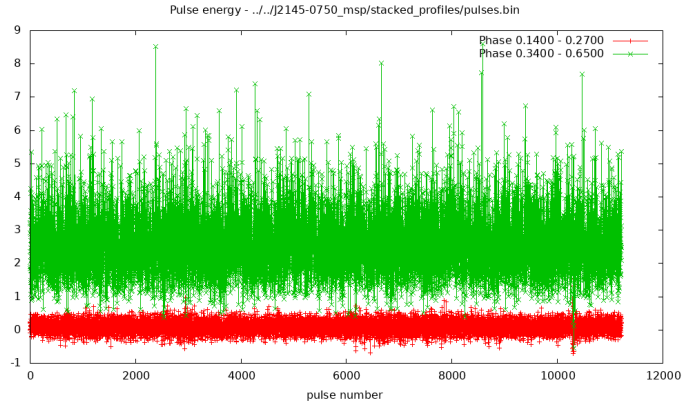

Fig 1 - Plot of on-pulse energy vs pulse number for PSR J2145-0750

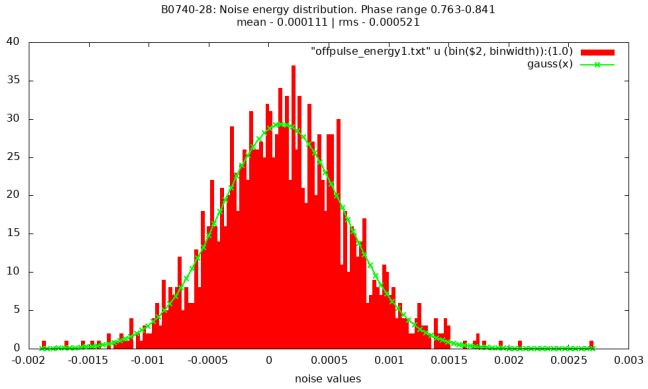

Fig 2 - Histogram of the off-pulse energies of individual pulses for PSR B0740-28

With this background, attention was focused towards 2 areas of development- (i) Making the single-pulse analysis software more useful and (ii) developing a real-time beamformer data monitoring tool for the GMRT.

Single-pulse analysis tool for pulsars

The tool (fig 3) was developed by past students of Prof Gupta, for enabling detailed analysis of individual pulses. For this it has a myriad of convenient features (fig 4) like finding pulses with nulling, plotting energy histograms, the autocorrelation of pulses etc. Its also possible to analyse 2 frequencies simultaneously for a pulsar. However, the tool had the following issues-

- There were 2 separate codes, one for dual-frequency analysis and one for single-frequency analysis and the 2 programs had a slightly different set of features.
- Some features gave wrong results for example when used in succession with some particular feature.
- The tool was not robust about handling invalid inputs which made it somewhat inconvenient.
- The list of data files that could be used in the tool was hardwired in the code, instead of allowing an easy way to analyse any new data file.
- Several other flaws regarding the user experience and display.

My work involved, understanding the tool, testing all the features and then fixing many of these issues about the user experience, making it more sensible. Using the

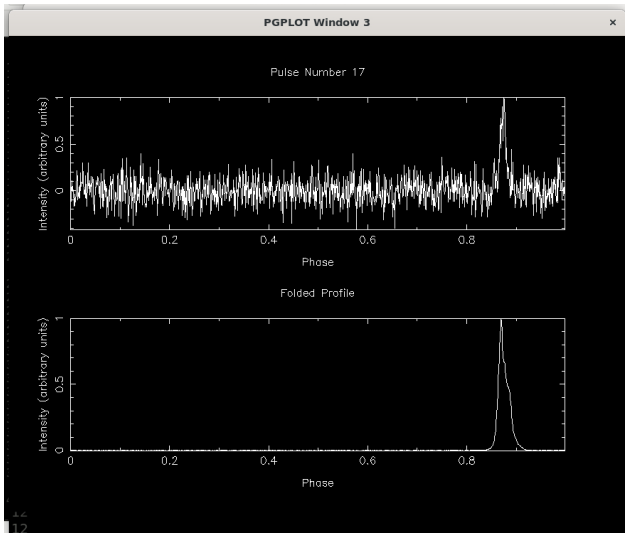

Fig 3 - Plot window of the single pulse analysis tool

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Instructions:
Use 'n' to go to next pulse
Use 'b' to go the earlier pulse
Use 'p <start phase> <end phase>' to set a phase range (Default is full period)
Use 's <phase shift>' to shift phase window (Phase shift should remain between 0 and 1 !)
Use 'f' to show folded profile
Use 'h' to hide folded profile
Use 'i <Integration>' to integrate profile
Use 'g <Pulse Number>' to get profile for a specified pulse number
Use 'l' to check for pulse nulling
Use 'u' to find all null pulses
Use 'a <Time lag>' to get autocorrelation plot for the current pulse, integration and phase r
ange
Use 'c <MinSNR>' to get list of pulse numbers above a given threshold
Use 't <MinSNR>' to get list of pulse numbers with peak above a given SNR
Use 'v <Time lag(ms)> to get the average ACF for the strongest pulses
Use 'y' to view the ADP for the specified window
Use 'k' to get instructions
Use 'q' to terminate program
Use 'w' to see on-pulse and off pulse energy histograms
Use 'x' to see grayscale plot of on-pulse energy as a function of pulse number
Folding profile. Please wait.

Default integration is 1 samples
```

Fig 4 - List of various features available in the tool

tool for any new data file was made easier, and it was made sure the features gave correct results. Furthermore the following additions were made to the tool-

- A new feature which enables user to restart the tool and choose a new pulsar without having to exit the tool and restart it.
- Modifying the histogram feature so that it plots the on- and off-pulse energy histograms on separate plots using user-given phase ranges.
- The currently ongoing task is to consolidate the 2 codes into a single tool with all the above improvements for both single and dual-frequency analysis of individual pulses.

Real-time beamformer data monitoring tool

The existing GMRT Pulsar Tool (gptool) is a very powerful software for pulsar observations. In the real-time mode, it can perform time and frequency domain RFI mitigation and flagging, dedispersion and folding on the incoming beamformer data. However, in order to run, gptool requires a text file called 'gptool.in' with all the observation paramters like frequency band being used, number of channels, sampling interval, source name etc. So even in a real-time mode, gptool requires manual entry of these parameters in gptool.in. The idea behind the real-time beamformer data monitoring tool is to circumvent the need for manual intervention and use gptool for monitoring real-time data from the beamformer in an automated way. Currently this tool has the following capabilities-

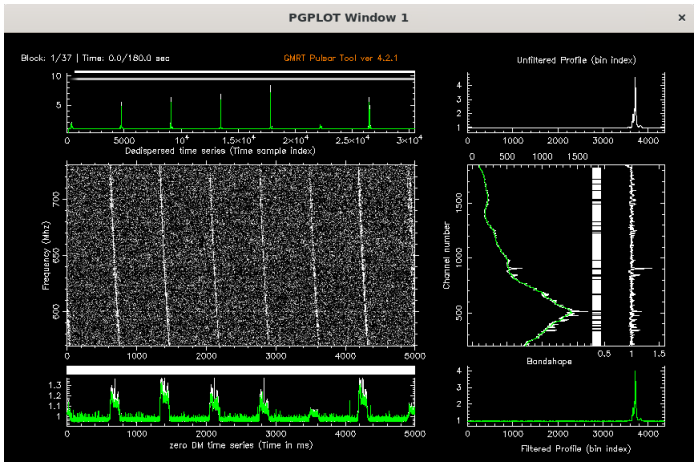

Fig 5 - gptool plot window

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#****Observation Paramaters****#
550             : Frequency band (lowest value in Mhz)
200             : Bandwidth(in Mhz)
1               : Sideband flag (-1-> decreasing +1->increasing)
2048            : Number of channels
0.16384         : Sampling Interval (in ms)
-------------------------------------------------
#****Pulsar Parameters****#
B0329+54        : Pulsar name
-1              : Pulsar period (in milliseconds)
-1              : DM (in pc/cc)
-------------------------------------------------
#****Dedispersion & Folding parameters****#
-1              : Number of bins in folded profile (-1 for native
0               : Phase offset for folding
12              : Number of coefficients for each polyco span (nCo
60              : Validity of each span (nSpan in mins)
12              : Maximum hour angle
-------------------------------------------------
#****Display Parameters****#
0               : Polarization channel to display (0-3 or -1 for a
5               : Display window size (seconds, 0-> pulsar period)
1               : Update mode                   (0-> automatic  1-> manual
```

Fig 6 - gptool.in and some observation parameters

- Detect whether there is an ongoing observation. If not, then it waits until there is one.
- Upon detecting the start of an observation, the tool extracts the observation parameters from the shared memory header, enters them in gptool.in and runs gptool.
- The tool can also detect whether the source name is a standard pulsar name. If not, then setting the Dispersion Measure to 0 and a custom value for the 'pulsar period' allows the tool to be used outside of pulsar observations as well.
- Stop gptool as soon as the current observation is stopped. Then again it is ready to detect a new observation.

As of this writing, more features and refinements are being added to the tool. After achieving a level of flexibility and robustness, the tool has several possible applications, some of which are -

- Checking the data quality during a pulsar observation. The gptool will show the average profile of the pulsar and bandshape for ready verification.
- Continuous monitoring of beamformer data regardless of source. This enables monitoring of the RFI level and with a suitable choice of the 'pulsar period' in gptool.in, one can look at, say, the level of the powerline interference.
- Characterise performance of individual antennas in an automated way. This will make use of the capability of the uGMRT to handle 4 beams simultaneously.
- Together with a graphical user interface and possibly setting it up on a web-based platform, the above things will be possible for a remote user on the internet.