REAL-TIME DETECTION OF NATURAL BRIEF EVENTS

IN A CORRUPTED ENVIRONMENT

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INTRODUCTION

The decameter band provides several examples of sporadic bursts drifting in the time-frequency plane. The best example is the radio emission from the Io-Jupiter electrodynamic circuit, called "S-bursts" (for short bursts), generally drifting from high to low frequencies at tens of MHz/sec for a few tens of msec. Instantaneous bandwidth is just a few kHz. Another example is the fine structure of solar radio emission sometimes associated to large type III bursts (excited by relativistic electron bunches through the solar corona). At least part of the Jovian S-burst activity can be predicted, for specific geometries observer-Jupiter-Io, but S-bursts may also be produced for other geometries, depending on the frequency, and with possibly positive time-frequency drifts. Solar fine structure activity is mostly unpredictable. Data bases on these radio bursts are thus scarce or incomplete.

A monitoring 24 hours a day would be useful to gather statistics about the occurrence of such events. But the time and frequency resolutions required for a proper understanding of the underlying physics would result in a huge amount of recorded data. Furthermore, post processing computation to detect interesting events would monopolize another computer and high Ethernet bandwidth for file transfer. The possibility of monitoring quasi-permanently the presence of burst activity while observing a given source, and recording at high rate only when this activity is present, would be a major advance allowing for in-depth studies over a large number or bursts, and could lead to significant new discoveries.

One solution is to perform a real time detection of potentially interesting events in order to trigger high resolution recording. Such an observation procedure requires a fast, highly reconfigurable radio receiver. R^3 (the Robust Radio Receiver at Nançay Observatory, France, see Fig. 1 and [1]) is used here to perform such a task. One of its 8 independent channels is used to perform permanent real time detection on low resolution data, with the FIne Spectral Structures Algorithm (FISSA) described below. When a candidate radio burst is detected, a second channel configured to provide high resolution data is triggered. A FIFO memory allows data acquisition to start prior to trigger time.

HARDWARE

R^3 is designed to perform astronomical observation in a polluted radio environment (see Fig. 2). The channel, consisting of a pipeline based on a Hunt Engineering HEPC9 board, is configured as follow: data acquisition and digital down conversion (DDC) of a 14MHz bandwidth is performed using a 14 bits ADC and a 1k-gate FPGA. Then, a 256 bins weighted FFT with 50% overlap embedded within a 3k-gate FPGA computes the low resolution spectral estimation of the signal. One TMS320C6203 (Texas Instruments) digital signal processor (DSP) runs FISSA. Data output is routed thought a PCI bus and stored on hard-drives. These data consist of a low resolution time-frequency (T-F) spectrogram of the signal intensity along with an index that reflects the presence of natural emissions. This index is used to trigger high resolution acquisitions using the others channels of R^3.

The detector is platform-independent so that the board can be used in other receivers than R^3. It is planned to be also used along with a Signatec PDA14 acquisition board that can digitize the 0-40 MHz band.

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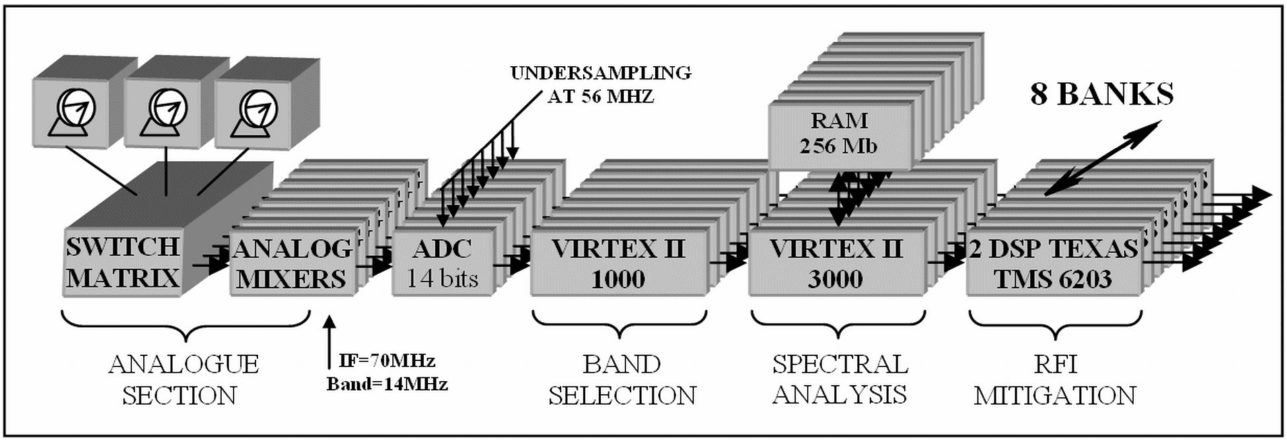

Fig. 1. Overview of R^3. The detector fits in one of the 8 independent channels.

FREQUENCY BAND OF INTEREST

One of the instruments available at Nançay Observatory is the Decameter Radio Telescope that covers the frequency band between about 10 MHz and 90 MHz, using two arrays of circularly polarized antennas. It is mainly aimed at the observation of Jupiter (10-40 MHz) and the Sun (20-80 MHz).

Fig. 2 illustrates the heavy pollution of the 10-90 MHz band by radio frequency interference (RFI). Periodic vertical bars are calibrating emissions while random sparse ones are broadband pulses such as lighting or car ignition coils. Horizontal patterns are radio-emitters such as the “Citizen Band” (26.96-27.41 MHz) or professional mobile communication bands (34.85-36.6 MHz). Man-made radio emissions are more intense during daytime. Fig. 2a-b are T-F spectrograms of Jovian emissions recorded at night (2a) and during the day (2b) in the same observer-Jupiter-Io geometry (which controls the occurrence of intense Jovian emissions - white horizontal bars highlight the predicted high occurrence probability intervals ; see [2]). The brief events such as Jovian S-bursts emissions that need to be detected can be seen on Fig. 2c.

ALGORITHM

The FISSA algorithm makes use of the frequency drift property to classify natural radio emissions because most RFI that could trigger the detector in this frequency band are either at fixed frequency or broadband short-lived pulses. Thus they appear as horizontal or vertical lines in the T-F plane. The high resolution setting of R^3 provides a 14 MHz-bandwidth T-F spectrogram with maximum resolutions of 6.8 kHz and 1.16 ms (660 Gbytes for 24 hours of continuous recording). The low resolution setting reduces the frequency resolution to 54.7kHz and time resolution can be adjusted down to 1.16ms per spectrum. FISSA slices up the T-F plane into adjacent images of 256 spectra $\times$ 256 channels (Fig. 3-left). The modulus of a 2D-FFT is computed on the log2 of the images (Fig. 3-middle). This transform is insensitive to position in the T-F plane. So, if a frequency drift is present anywhere in the original image, this information is gathered in the center of the image transform under the form of an oblique elliptical shape. Similarly, frequency lines or wideband pulses are gathered in the center of the 2D-FFT under the form of a vertical cross. This area is removed to prevent the detector from detecting those RFI. An index based on central channel of a Radon transform of the 2D-FFT (Fig. 3-right) is calculated as the ratio between the maximum value of the channel and its mean value. Above a selected threshold, the index triggers high resolution recording. Low resolution T-F spectrograms and relevant high resolution ones are time-stamped and written on disk.

The user can select a specific range of frequency drift values over which computing the index, depending on the nature of emissions to detect. This is done by choosing the adequate time resolution of the low rate acquisition and the interval of angles to be considered for the maximum of the Radon transform.

REAL-TIME IMPLEMENTATION

The log2 function of 32-bits integer data is implemented as the location of the highest non-zero digit in the 32-bits word. It is equivalent to round toward zero the floating point value return by the log2 function. This approximation never

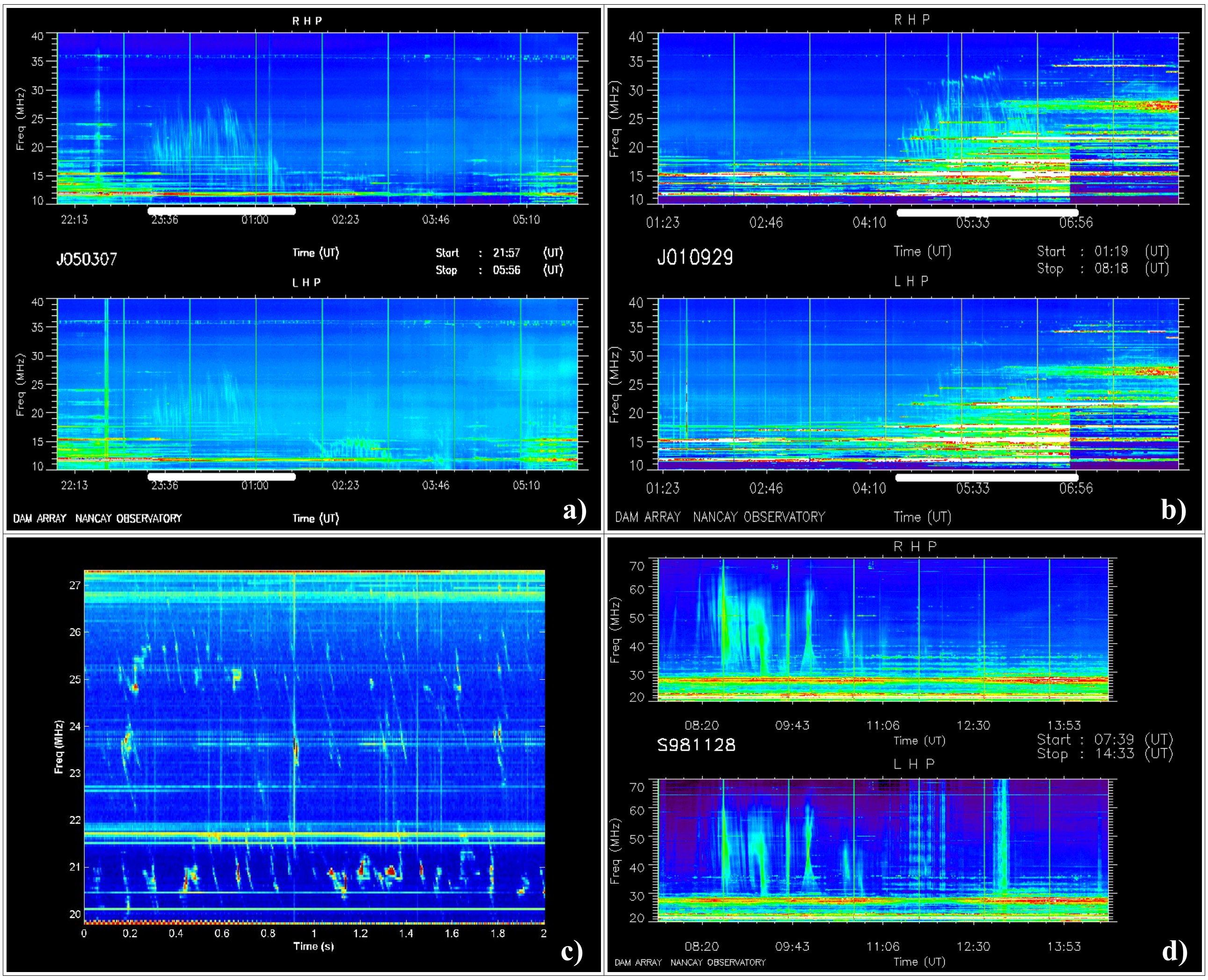

Fig. 2. a) Frequency band of Jupiter emissions at night and b) in the morning 6 months later but in the same observer-Jupiter-Io geometry (white line). c) Higher resolution record of fine structure Jovian emissions with a SAO at Nançay Decameter Radio Telescope . d) Frequency band of Sun emissions.

underestimates the real results by more than 3dB. This is consequently the lowest SNR that can be detected with FISSA. Lower SNR could be reached with an improved log2 approximation (fixed-point integer with non-zero fraction length).

The θ-ρ plane generated by the Radon transform is poorly used in the following steps of the algorithm. Only the center channel (i.e. ρ=0) is needed since the 2D-FFT gathered all frequency drifts in the center of the image. The Radon transform is interesting for the theoretical study of FISSA but implementation is greatly improved by computing its center channel simply as the integration along a line of slope θ passing through the center of the 2D FFT. This channel is thus estimated simply as the sum of the closest pixels of such lines for every required angle. The coordinates of the corresponding pixels are tabulated for every angle value, in order to reduce the amount of calculations required for the sine function. The user can define the range of angles to be considered for detection, as well as the angular resolution within this range.

CONCLUSION

Further data processing, such as shape recognition, can be driven on high resolution data that is now reduced to a set of possibly interesting events. Preliminary tests of detection have shown a reduction of the amount of high resolution data of 62% during a period of high S-burst activity and 94% for a period of low S-burst activity. Low resolution data along S-bursts indexes represent less than 0.05% of the full time high resolution survey data.

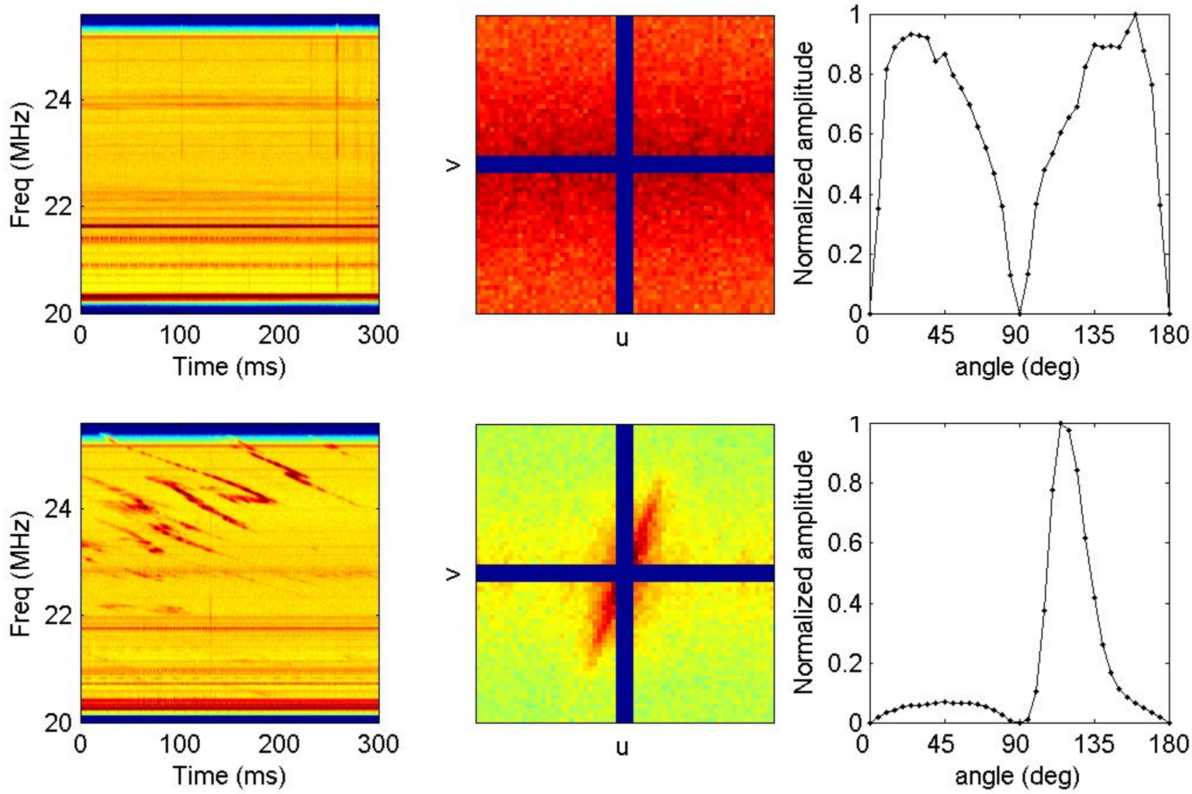

Fig. 3. (Left to right) Original T-F plane, 2D-FFT, center channel of Radon Transform. (Top to bottom) Without and with S-bursts.

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