The Experimental Study of Possibility for Pulsar Signal Detection

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***Abstract*—A possible variant of the signal processing for detection of weak pulsar signals is presented in this paper. The signal processing incudes three basic stages: epoch folding, moving average filter with a jumping window and adaptive signal detection. The signal processing proposed in the paper was verified with real experimental signal records from pulsar B0329+54 by the Westerbork Synthesis Radio Telescope in Westerbork, the Netherlands.**

Keywords—Pulsar signal detection, estimation, navigation

I. INTRODUCTION

Pulsars are fast rotating neutron stars that emit radio waves, which is received on earth as a series of very stable fast periodic pulses. A number of studies [1-4] have been performed on navigating using pulsar signals based on principles similar to GPS and Glonass. This new technology can be an alternative to standard navigation based on radio tracking by GPS ground stations, without the disadvantages of uncertainty increasing with distance from Earth and the dependence on the ground control. Since the radio signal from the pulsar is a low-power then detection of signal is very difficult. The received signals from pulsars there are signal to noise ration from -90dB to -40dB.

Since each pulsar has a unique period, in [1] is applied epoch folding algorithm to shape the pulsar pulse, remove noise, and find the pulsar. Folding is similar to integration except that in folding, the data is broken into a sequence of discrete intervals corresponding to the period of the expected pulsar and then added (or folded) ensuring that the pulsar signal is reinforced with each fold, while the noise approaches a mean zero. The epoch folding method is convenient, but the integration time is too much. It is equal to the number of period of repetition of the signal from the pulsar multiplied by the length of the period.

In the paper, we will discuss the possibility to increase the signal to noise ratio by using moving window processing in the period of signal. To improve the signal to noise ratio is possible by using sliding or jumping window in time domain signal. The processing time by using sliding window is large when the number of samples are large. In the paper, we proposed an algorithm for non-coherent integration by using jumping average window over recording signal in the period of signal.

As a result of this processing, the number of samples in the record will be reduced in proportion to the number of cells in jumping window. The small number of samples will increase the further signal processing. In the paper, we will research the influence of length of jumping window over the signal to noise ratio.

II. SIGNAL PROCESSING

In this work, we propose a possible signal processing algorithm for increasing of signal to noise ration and detection of weak pulsar signals. The algorithm includes the following stages: epoch folding of data during *N* repetition periods of the input data; integration by using jumping average window; estimation of SNR at the moving window output and CFAR detection [5, 6] of a pulsar signal (see Figure1).

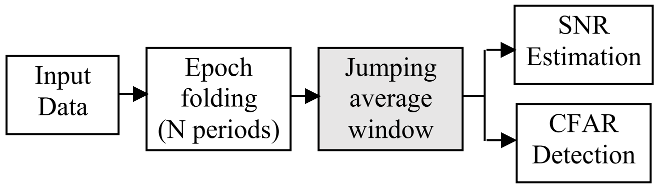

Fig. 1. Block-scheme of signal processing

A. Epoch folding

Epoch folding method is similar to integration technique. It is convenient to be used for periodic signals in the presence of white Gaussian noise. If the period P of a particular pulsar is known, than the pulsar's average pulse shape (pulse profile) can be determined using the epoch-folding procedure. The integration of the received signal during N sequential repetition periods of the input data (usually called as epoch folding) is done as non-coherent. It is the standard way that is implemented in most of radio observatories. When the number of integrated periods grows, the pulsar signal reinforces with each integrated period while the noise approaches to a zero mean. To illustrate this process see Figure 2.

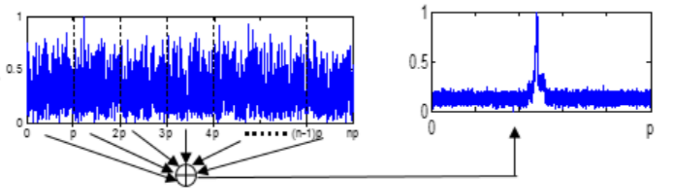

Fig. 2. Epoch folding process

B. Moving Average Filter with a Jumping Window

The Moving Average Filter with a Jumping Window (MAFJW) is a modified version of the Moving Average Filter (MAF). It divides the period with N samples into L non-overlapping intervals (windows) of size M and calculates the average of samples in each interval. Therefore, the MAFJW acts not only as a low- pass filter but a decimator as well. When the signal processing is carried out in the time domain, the use of the MAFJW can be very useful in the sense of reducing the processing time.

Jumping window integrate Nw sempels in the pulsar period. To illustrate this process see Figure 3.

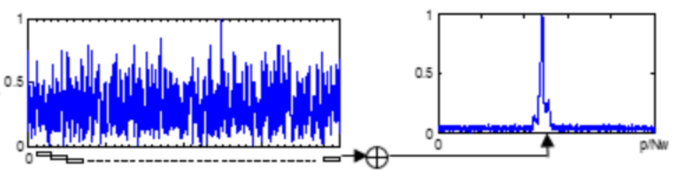

Fig. 3. Jumping windowing process

C. Estimation of SNR

Let s_w, $(s+n)_w$ and n_w are the signals at the output of the jumping window when its input signals are respectively the desire signal s, the "signal+noise" $(s+n)$ and the noise n. Bearing in mind that, in practice, the input of the jumping window is an additive mixture of the desired signal s and noise n, i.e. $(s+n)$, the output SNR of the moving window can be estimated as [7, 8]:

$$SNR_{out(s+n)} = P_{(s+n)w} / P_{(n)w} \tag{1}$$

Where $P_{(s+n)w}$ is the peak power of the signal $(s+n)$ at the MAFJW output, and $P_{(n)w}$ is the average power calculated at the jumping window output in the intended noise zone. The output SNR of the jumping window estimated by (1) directly influences on the detectability of desire signal s using CFAR detection algorithms.

D. CFAR Detection

The CFAR detection approach is based on the criterion of Neyman – Pearson. According to this criterion, the following algorithm can be used for testing a simple hypothesis H_1 (pulsar signal is present) against a simple alternative H_0 (pulsar signal is absent):

$$\begin{array}{ll} H_1: & if \ \max\{P_y[k]\} \geq T_{fa} \sum_{l=1}^{L} P_y'[l] \\ H_o & \qquad\qquad otherwise \end{array} \tag{2}$$

In the decision rule (2), $P_y[k]$ is the signal power samples at the CFAR detector input, L is the size of a reference window used for estimating of the noise power and $P'_y[l]$ are the signal power samples within the reference window. In order to determine the reference window all input power samples $P_y[k]$ are sorted in the ascended order and the first L sorted samples form the reference window. The detection constant T_{fa} is determined in accordance with the probability of false alarm maintained by the detection algorithm. We assume that the hypothesis H_1 is verified in only one single sample, which contains the maximal value of the signal power [7, 8].

III. Experimental Results

The experimental data contain the noisy signal received from pulsar B0329+54 at the Westerbork radio observatory (Figure 4). The experimental data are sampled at a frequency of 40 MHz, and the number of samples of the input signal within a repetition period is 28582316 ≈ 2.8e7.

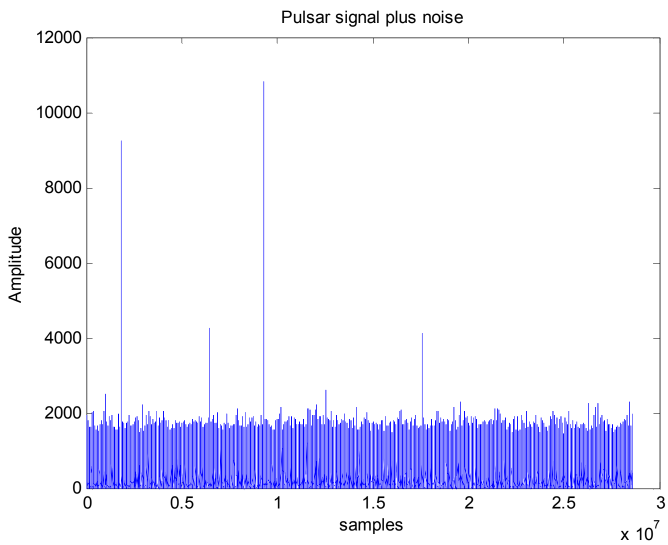

Fig. 4. Pulsar signal (1 period)

If we use only the epoch folding algorithm with 169 integrated periods (without MAFJW), we obtained the result shown in figure 5. When the number of integrated periods increase then the pulsar signal to noise ratio also increase.

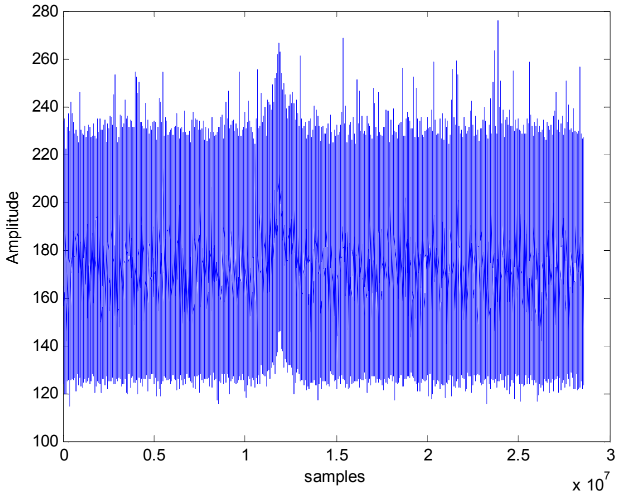

Fig. 5. Pulsar signal after epoch folding (169 periods)

The epoch folding method is convenient, but the integration time is too much. In the paper we apply MAFJW to reduce the time to detect the pulsar signal. The results after one epoch folding and MAFJW with window length of the filter 100 cells is shown in figure 6.

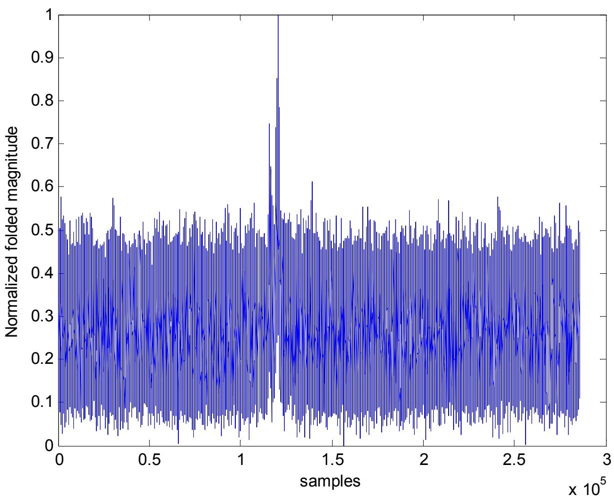

Fig. 6. The signal after 1 epoch folding and window length 100 cells

Increasing the window length of 100 000 cells, results in increased signal to noise ratio as it is shown in figure 7. In this case the number of samples in the record will be reduced in proportion to the number of cells in jumping window. The small number of samples will increase the further signal processing. The key problem concerned with the Jumping Average Window (JAW) is the optimal choice of the jumping window length. When choosing the window length of the JAW we must take into account not only the level of suppression of the noise variance, but the degree of distortion of the useful signal immersed in noise. The optimal window size of the MAFJW can be determined only in cases where the spectrum of the signal is known $\Delta f = 400Hz$ and bounded by a certain frequency and the noise power does not exceed a certain level (figure 8).

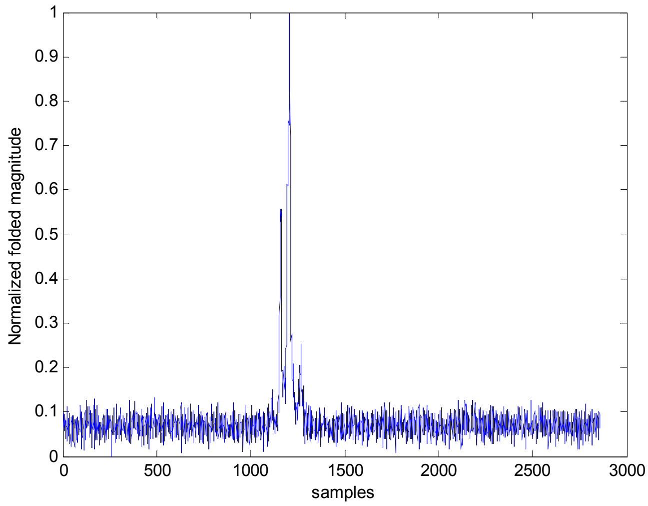

Fig. 7. The signal after 1 epoch folding and window length 100 000 cells

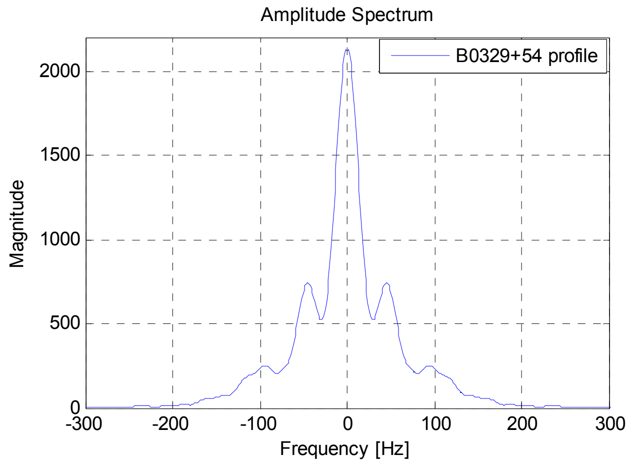

Fig. 8. Amplitude spectrum

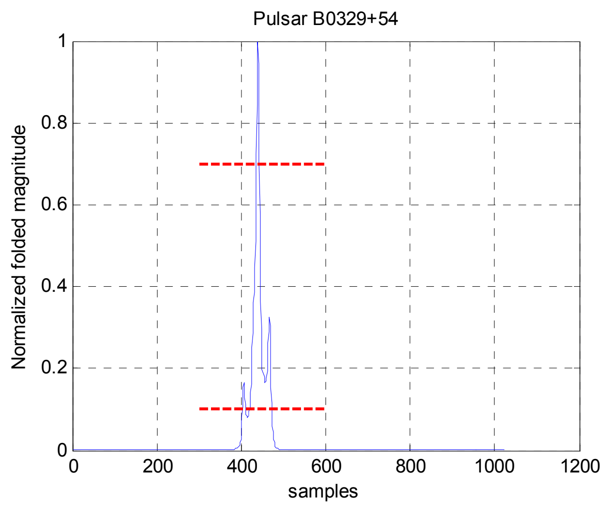

Fig. 9. Pulse profile of pulsar B0329+54

The maximum number of samples that can be used in the jumping window are:

$$N_{\max} = f_s / f_{s,new} \quad (3)$$

Where $f_s = 40MHz$ is a sampling frequency, $f_{s,new}$ is a new sampling frequency. In order not to disturb the Nyquist theorem is necessary $f_{s,new} \geq \Delta f$.

The maximum number of samples that can be used in the jumping window and to not distort the signal quality is $N_{\max} = 100000$. Increasing the SNR to increase the detection probability of the pulsar signal is possible by additional increasing of the size of the jumping window, but the signal at the output of the filter will be distorted. Choosing the size of jumping window in this case can be coordinated with the size of the signal from the pulsar levels 10% and 70% from the signal amplitude or 2e+5 and 2e+6 cells (fig. 9). In this case we lose the signal quality (Figure 10 and 11), but increased SNR.

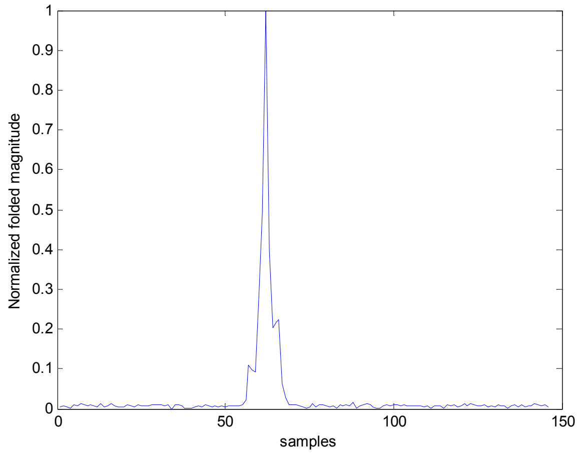

Fig. 10. The signal after 13 epoch folding and window length 2e+5 cells

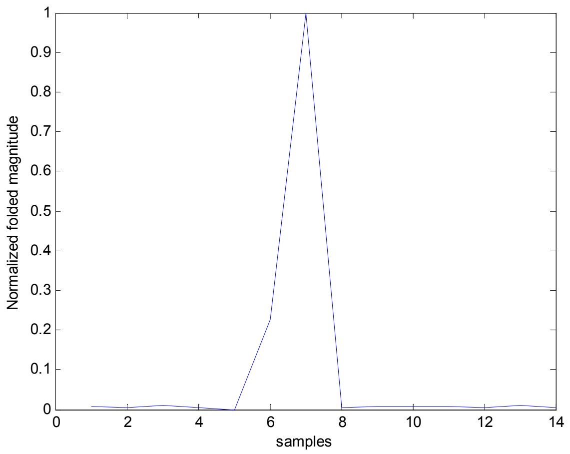

Fig. 11. The signal after 13 epoch folding and window length 2e+6 cells

In the table 1 are shown the SNR for different values of window length and epoch folding. The results are obtained for real pulsar records with pulse period 28582316 samples.

TABLE I. SNR FOR DIFFERENT VALUES OF WINDOW LENGTH AND EPOCH FOLDING

Jumping window N cells	$f_{s,new}$ Hz	Epoch folding		
		1 period	13 periods	169 periods
		SNR in [dB]		
1e+2	400 K	5.81	5.85	8.05
1e+3	40 K	7.35	8.9	12.74
1e+4	4 K	11.53	14.16	18.04
1e+5	400	16.58	19.88	22.86
2e+5	205	17.4166	20.3155	24.2688
2e+6	20.5	18.0945	21.6581	25.3501

IV. Conclusions

The obtained results show that the presented algorithm can be successfully used for processing and detection of pulsar signals. Using Moving Average Filter with a Jumping Window in time domain we increase the signal to noise ratio and reduce the detect time.

Acknowledgment

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