Pulsar Signal Detection Using Hough Transform

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***Abstract*—Pulsars are rotating neutron stars that emit electromagnetic radiation at regular intervals and can be used for navigation and for detection of meteoroids and asteroids. The detection of a pulsar signal for a short time (in real time) is difficult because the signals are very weak. In this paper, we develop a detection algorithm, which includes three basic stages: moving average filter with a jumping window, Hough transform and detector. The algorithm proposed in the paper was verified with pulsar signals from Jodrell Bank Centre for Astrophysics.**

Keywords-Pulsar signal detection, Hough transform, signal processing, moving average filter with a jumping window

I. INTRODUCTION

Pulsars are fast rotating neutron stars (see Figure 1) that periodically emit broadband electromagnetic pulses [1]. The emission period is thought to be the same as the rotation period. Although individual pulsar pulses vary in strength and shape, the average pulse shape is stable and characterizes each pulsar.

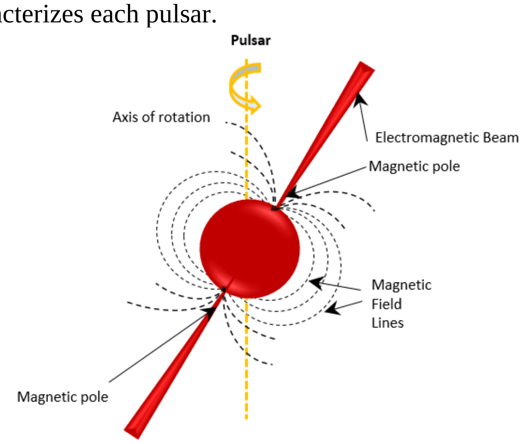

Figure 1. Pulsar

The idea of using pulsars, rapidly rotating neutron stars, for orientation in space is not new [2]-[4]. It is similar to the oldest idea - navigation of ships centuries ago through observation of the visible stars with sextants and using the star and sea charts. This approach is similar, but the difference is in the reception of radio signals instead the light emission of stars.

A similar approach for navigation by satellites is in Global Navigation Satellite System (GNSS). This requires to search very specific, fast and effective methods and algorithms for detection and estimation of their parameters.

Earlier, the practical realization of the idea of space navigation was difficult, first, the insufficient number of known pulsars, and secondly - sophisticated technology to detect them. But in recent years, the situation has changed significantly. Since the discovery of the first pulsar in 1967, approximately 2100 pulsars have been found.

The pulsar signal can be used also for observation and detection of falling cosmic objects as asteroids and meteoroids [14]. This information would be useful in creating early warning systems.

The main difficulty in detecting a signal from the pulsar by radio telescopes is the low Signal-to-Noise Ratio (SNR) at the receiver input (from -40 dB to -90 dB). Another difficulty in the study of the pulsars is a great consumption of time needed for detecting the signal from them, about 1-2 hours [5]-[11], [15].

Since each pulsar has a unique period, in [4] 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 [5] it is discussed the possibility to improve the signal to noise ratio by using Moving Average Filter with a Jumping Window (MAFJW) in time domain 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 this paper, we propose the use of Hough transform as method for detecting of pulsar pulse sequence. This algorithm is tested over real pulsar signals. In the previous works, the Hough Transform is used to detect straight lines in image. This transformation is also used in algorithms for detecting of target and trajectories of moving targets [13], [16]. In this paper, we offer an unconventional approach to

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detecting pulsar signal using Hough transform. In the further work will be evaluated the efficiency of the proposed algorithm.

Section 2 describes the algorithm for signal processing. Section 3 discusses the experimental results. Finally, section 4 draws conclusions based on the obtained results.

II. SIGNAL PROCESSING

The considered algorithm of signal processing of the pulsar signals experimental data is shown in Figure 2. It includes the following stages: filtration by the MAFJW; Hough transform and, finally detector.

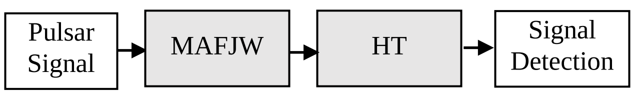

Figure 2. Block-scheme of signal processing

A. *Filtering by the MAFJW*

The aim of this study is to examine the possibility to increase the signal to noise ratio of the received pulsar signal by means of one modification of a Moving Average Filter, which uses the Jumping Window (MAFJW). It takes *N* samples of input at a time and take the average of those N-samples and produces a single output point. It is a very simple structure that comes handy for scientists and engineers to filter an unwanted noisy component from the input data.

$$y[n] = \sum_{k=-N}^{N} \frac{1}{2N+1} x[n-k], \quad n=N+1, 2N+1,.., MN+1 \qquad (1)$$

Where *n* contrary to the traditional Moving Average Filter (MAF) where the number of output samples is equal to the number of input samples, the MAFJW reduces the number of output samples *N* times, where *N* is the length of the Jumping Window. The number of input samples is *MN*, and the number of output samples is *M*. Therefore in contrary to the traditional Moving Average window, 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.

B. *Hough Transform*

The standard Hough transform and the related Radon transform have received much attention in recent years [13]. Using them makes possible the transformation of two-dimensional images with lines into a domain of possible line parameters, where each image line corresponds to a peak, positioned at the respective line parameters. For these reasons, many line detection applications appeared within the image processing, computer vision, and seismic research areas. The use of the standard Hough transform (SHT) for target detection and track determination in white Gaussian noise is introduced by Carlson, Evans and Wilson in [12]. The standard Hough transform maps points from trajectory of the observation space termed as range-time $(r-t)$ data space into curves in Hough parameter space. The trajectory from the observation space can be defined by the angle θ of its perpendicular from the origin and the distance ρ from the origin to the line along the perpendicular.

$$\rho = r\cos(\theta) + t\sin(\theta) \qquad (2)$$

where r and t are coordinates measured from the origin of ρ and θ axis in the lower left. The result of transformation is a sinusoid with magnitude and phase depending on the value of the point in range-time $(r-t)$ space.

Each point in the Hough parameter space corresponds to one straight line in the $(r-t)$ space with two parameters (ρ, θ). Each of the sinusoids corresponds to a set of possible straight lines through the point. If a straight line exists in the $(r-t)$ space, by means of the Hough transform it can be viewed as a point of intersection of sinusoids defined by the Hough transform. The parameters ρ and θ define the linear trajectory in the Hough parameter space, which could be transformed back to the $(r-t)$ space showing the current distance to the target.

C. *Detection algorithm*

The detection algorithm is based on threshold processing of the cells in the Hough parametric space [13]. According to this algorithm, we tested a simple hypothesis H1 (pulsar signal is present) against a simple alternative H0 (pulsar signal is absent). Each cell from the Hough parameter space is intersected by a limited set of sinusoids obtained by Hough transform. If the number of intersections in any of the cells in the parameter space exceeds a fixed threshold (T_M), pulsar signal detection is indicated.

III. RESULTS

In this study, the experimental records of the signal received from the pulsar B0329+54 provided by Jodrell Bank Centre for Astrophysics are used. This is the brightest radio pulsar in the northern sky. Otherwise this pulsar is a typical, normal pulsar, rotating with a period of 0.714520 seconds, hence the star makes about one and a half turn in a second, giving it a locomotive kind of sound. We can see in Figure 3 that each pulse has a different structure, hence the beam of this cosmic lighthouse is constantly changing in shape. This recording has been made with the Lovell telescope in Jodrell Bank.

The signal in Figure 3 is obtained after signal processing procedure which is about 2 hours. When the SNR is about -20 dB, the pulsar signal will be as in Figure 4. The representation of the pulse signal in a matrix so that each pulse period is in a separate order is shown in Figure 5. When we use moving average filter with jumping window

(MAFJW), the output SNR increases. The filter output for length of the jumping window N=100 is shown in Figure 6. The contour of the MAFJW output is shown in Figure 7. In the Figure 8 is shown Binary integration of data in Hough parameter space. If the number of binary integrations (BI) of data in the Hough parameter space (of intersections in any of the cells in the parameter space) exceeds the detection threshold, then pulsar signal is detect.

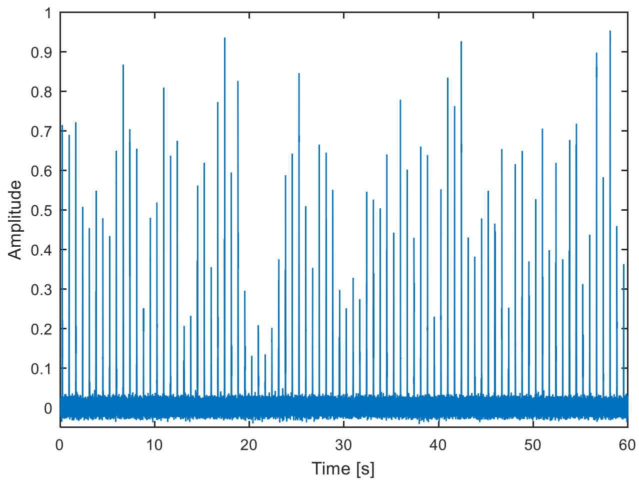

Figure 3. Pulsar signal (B0329+54)

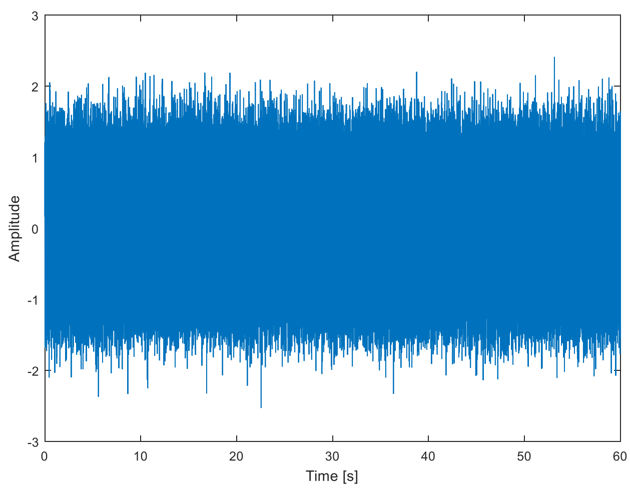

Figure 4. Pulsar signal B0329+54 and noise (SNR= - 20dB)

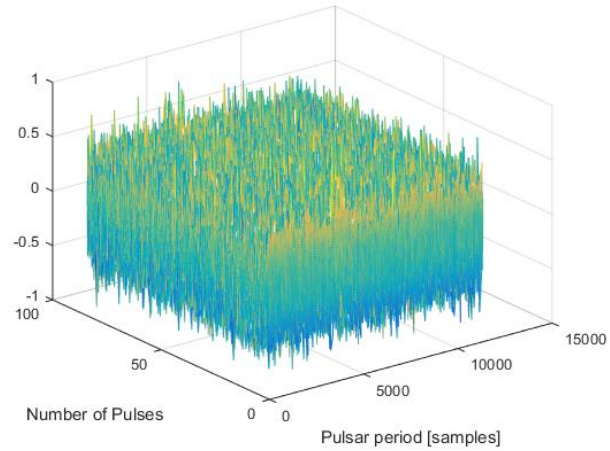

Figure 5. Pulsar signal

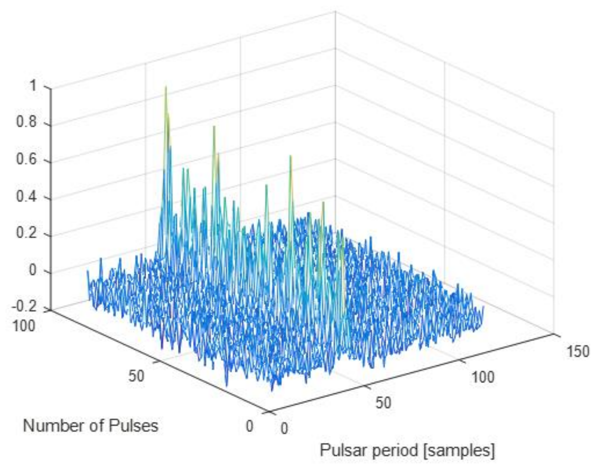

Figure 6. Pulsar signal after MAFJW (N=100)

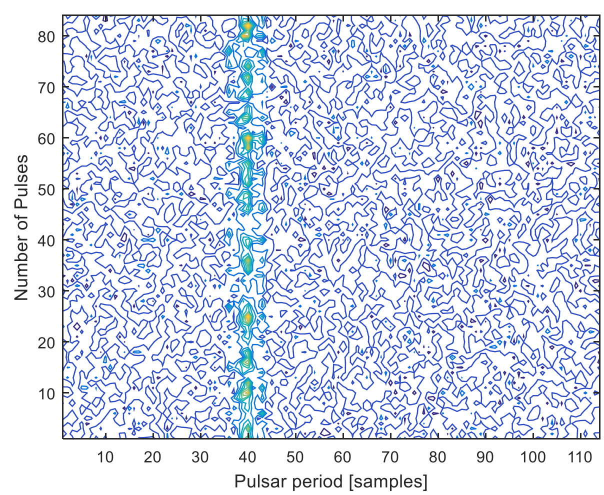

Figure 7. Contour of the pulsar signal after MAFJW (N=100)

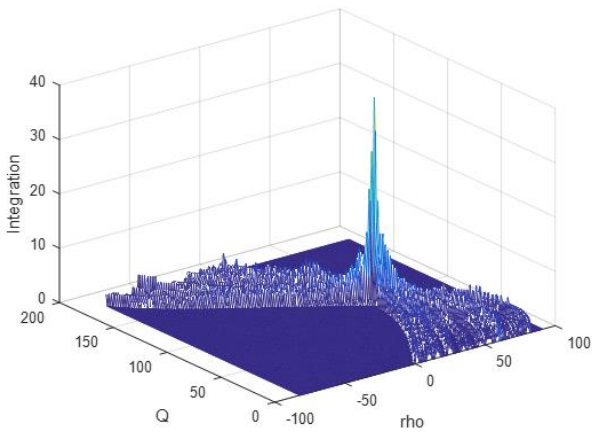

Figure 8. Hough transform the pulsar signal after MAFJW (N=100)

IV. CONCLUSIONS

The obtained results show that the presented algorithm can be successfully used for processing and detection of pulsar signals. The signals from pulsars are very weak and difficult to detect. The SNR can be improved using the Moving Averaging Filter with a Jumping window. The pulsar signals are periodic with a highly stable pulse-repetition frequency allowing the pulse signal to form a straight line in the computer space. The Hough transform is a popular tool for line detection due to its robustness to noise and missing data. The presence of the Hough transform further enhances the detection of the pulsar signal. In the next work, the efficiency of the proposed algorithm will be evaluated.

ACKNOWLEDGMENT

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REFERENCES

[1] J. Sala, A. Urruela, X. Villares, R. Estalella and J. Paredes, "Feasibility study for a spacecraft navigation system relying on pulsar timing information", Final Report, 03/4202, ARIADNA Study, June 2004, p. 92.

[2] P. Buist, S. Engelen, A. Noroozi, P. Sundaramoorthy, S. Verhagen and C. Verhoeven, "Principles and Potential of Pulsar Navigation", Proceedings of the 24th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2011), Portland, OR, September 2011, pp. 3503-3515.

[3] P. Buist, S. Engelen A. Noroozi, P. Sundaramoorthy, S. Verhagen and C. Verhoeven, „Overview of Pulsar Navigation: Past, Present and Future Trends", Journal of the Institute of Navigation, vol.58, № 2, 2011, pp.153-164.

[4] N. White, F. Nagase and A. Parmar "X-Ray Binaries", Cambridge Astrophysics Series, 1995, p. 662.

[5] I. Garvanov, C. Kabakchiev, V. Behar, and M. Garvanova, " The Experimental Study of Possibility for Pulsar Signal Detection", The Second International Conference "Engineering & Telecommunications – En&T 2016", Noevember 28-30, Moscow-Dolgoprudny, Russia, 2016, pp. 68-72, doi: 10.1109/EnT.2016.023.

[6] C. Kabakchiev, V. Behar, P. Buist, I. Garvanov, D. Kabakchieva, N. Gaubich and M. Bentum, "Study of CFAR Algorithms for Signal Acquisition in Radio Pulsar-Based Navigation", 21st Saint Petersburg International Conference on Integrated Navigation Systems 2014, Saint Petersburg, Russian Federation, 2014, pp. 186-194.

[7] C. Kabakchiev, V. Behar, P. Buist, I. Garvanov, D. Kabakchieva and M. Bentum, "Time of Arrival Estimation in Pulsar Based Navigation Systems", Signal Processing Symposium, Debe, Poland, 2015, pp. 1-5, doi: 10.1109/SPS.2015.7168287.

[8] C. Kabakchiev, V. Behar, P. Buist, R. Heusdens, I. Garvanov and D. Kabakchieva, "Detection and Estimation of Pulsar Signals for Navigation", International Radar Symposium, Dresden, Germany, 2015 pp. 688-693, doi: 10.1109/IRS.2015.7226320.

[9] I. Garvanov, C. Kabakchiev, V. Behar and M. Garvanova, "Target detection using a GPS Forward-Scattering Radar". IEEE Second International Conference "Engineering & Telecommunications – En&T 2015", Moscow-Dolgoprudny, Russia, 2015 -pp. 29-33, doi: 10.1109/EnT.2015.20.

[10] D. Izvorska, "On the something application of axial and central symmetry to work on construct problems", II International seminar Symmetry: theoretical and methodological aspects, Astrakhan, 2007, pp. 194-199.

[11] S. Slavova and D. Izvorska, "Using Maple in Linear Algebra", International Scientific and Methodical Conference, Penza, 2008, pp. 218-230.

[12] B. Carlson, E. Evans and S. Wilson, "Search Radar Detection and Track with the Hough Transform", IEEE Trans., vol. AES - 30.1.1994, Part I, pp. 102-108; Part II, pp. 109-115; Part III, pp. 116-124.

[13] I. Garvanov I., "Multisensor Data Association by Using the Polar Hough Transform", Book Title "Practical Issues of Intelligent Innovations", Chapter No.: 11, Springer International Publishing, 2018, pp. 255-276, doi:10.1007/978-3-319-78437-3.

[14] C. Kabakchiev, V. Behar, I. Garvanov, D. Kabakchieva, A. Kabakchiev, H. Rohling, M. Bentum and J. Fernandes, "Separation of Pulsar Signals in FSR System", International Radar Symposium 2018, 28-30 June, 2018, Bonn, Germany.

[15] H. Liang and Y. Zhan, "A Fast Detection Algorithm for the X-Ray Pulsar Signal", Mathematical Problems in Engineering, Volume 2017, pp. 1-5, doi:10.1155/2017/9607821

[16] E. Davies, "The generalized Hough transform", Book Title: Computer Vision: Principles, Algorithms, Applications, Learning, Chapter No.: 11, Elsevier, 2018, pp. 299-340, doi:10.1016/B978-0-12-809284-2.00011-3