Real-time radar Doppler processing

Rossen Miletiev[1]

Abstract - This paper discusses the algorithm for coherent Doppler processing using consecutively changed PRFs and nonparametric spectral estimation method for the nonuniformly sampled data sequence. The described Doppler processing algorithm provides improved performance for target detection, especially in low SNR environments, and it is suitable for search Doppler radars with fast frequency changes and a relatively small number of echoes from a target.

Keywords – Doppler processing, real-time

I. Introduction – Radar serves to detect objects within the area of observation and to estimate their position coordinates. The echo characteristics provide information such as the range, angular location of the target, its trajectory if it is moving and predict future location [1-3]. The Doppler processing of the reflected signal is the primary tool at the detection, identification and classification of the targets and an estimation of its mean target velocity and position coordinate. It improves the moving target improvement factor of the system. Hence it improves the performance of the detector. A wide range of techniques for Doppler-based clutter suppression are practical due to advances in signal processing [4-6].

They often utilize parametric estimation methods, which require prolong computing time and impede the real-time operation. For that reason, the Doppler processing algorithm is described below, which is based on *FFT* technique and possesses the enhanced spatial resolution.

II. System design – The main problem, which the proposed algorithm decides, is associated with the relation between the target azimuth coordinates and its spectral characteristics. Therefore, the expedient *PRFs* alternation had to be chosen. If the radar transmits the first *n* pulses with the first *PRF* and the second *n* pulses with the second one then the analyzed data segment contains the different data bits of the each *PRF* and the spectral analyze requires the prolong computation time due to impracticable *FFT*. Therefore the real-time sliding spectral estimation is impossible. If the data sequence from each *PRF* is collected at blocks and transformed to frequency domain by *FFT*, then the frequency data bits are not associated with the target azimuth coordinates. For that reason the consecutively changed *PRFs* are used, i.e. the odd pulses are transmitted with the first *PRF* and the even pulses – with the second one.

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This choice possesses the next advantages:

- Every data segment contains *N/2* bits for each *PRF*
- The spectral estimation method is based on *FFT* technique to ensure the great computing efficiency
- The 2D output matrix is produced for each returned echo. This fact allows to determine the target azimuth coordinate
- The spatial resolution is increased, because the algorithm can resolve multiple targets, which have the same azimuth coordinates, but different radial speed. Therefore, the algorithm gives an account of the finite dimensions of the antenna radiation pattern at *E* and *H*-plane.

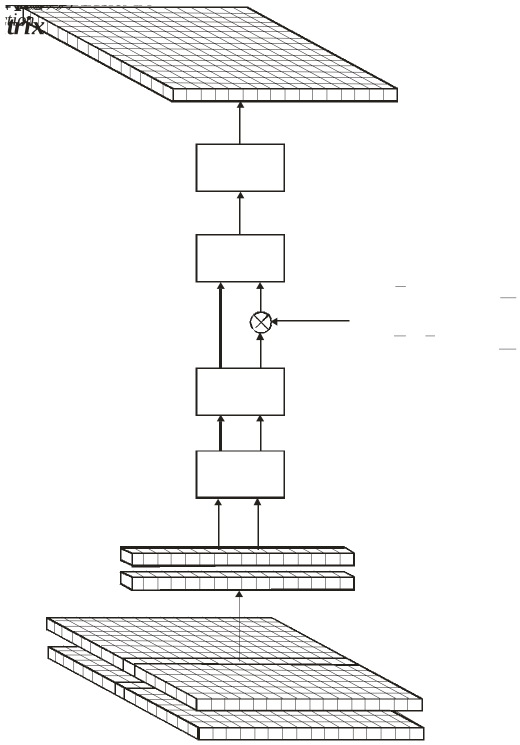


Fig.1. Real-time Doppler processing algorithm

The proposed algorithm for real-time Doppler processing is based on the accepted way of the *PRFs* alternation. The algorithm diagram is shown at fig.1 and contains the following steps:

- The discrete data sequence from the pulse compression matrix is divided in two sequences, which contain the odd and even bits respectively
- The created sequences are multiplied by window function to avoid the spectral leakage. The *Hamming* window is used due to its low sidelobe levels

- The $N/2$ point *FFT* is applied to the odd and even windowed sequences
- The spectrum coefficients of the even sequence $X(2k+1)$ are corrected with the phase factor $\exp\left[-j\frac{2\pi}{N}m(1-\rho)\right]$, according to the reported spectrum estimation method [7]
- The segment frequency response is estimated by addition the spectrum coefficients of the odd and corrected even sequence
- The power spectrum is calculated from the segment frequency response
- The proposed algorithm is repeated from step 1 by shifting the segment to one bit to realize the sliding spectral analysis

III. Numerical example – The proposed Doppler processing algorithm is simulated using *MATLAB®* routine. The simulations are implemented at the following conditions:

1. A single target is presented at the scan area
2. If the target azimuth angle is equal to φ_0, then the input data sequence describes the scanning results from the azimuth range $\varphi = (\varphi_0 - 10^0; \varphi_0 + 10^0)$
3. The antenna radiation pattern is described by the equation and is shown at fig.2:

$$|F(\varphi)| = \left|\frac{\sin\frac{x_0}{\theta_0}\varphi}{\frac{x_0}{\theta_0}\varphi}\right| \cdot \frac{\theta_0^2}{|\theta_0^2 - \varphi^2|},$$

where $x_0 = 2.2629$ - constant, which describes the system parameters

$2\theta_0 = 0{,}9\deg$ - antenna beam width at -3dB

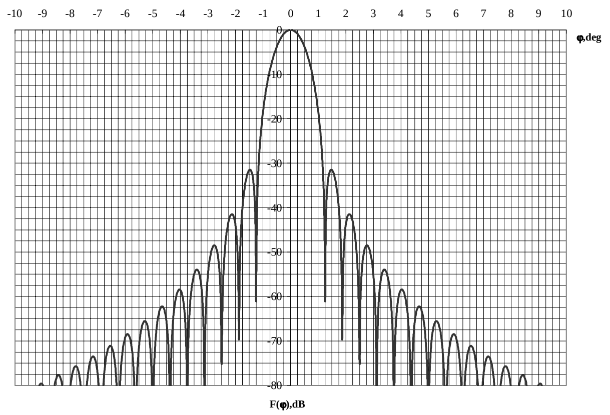


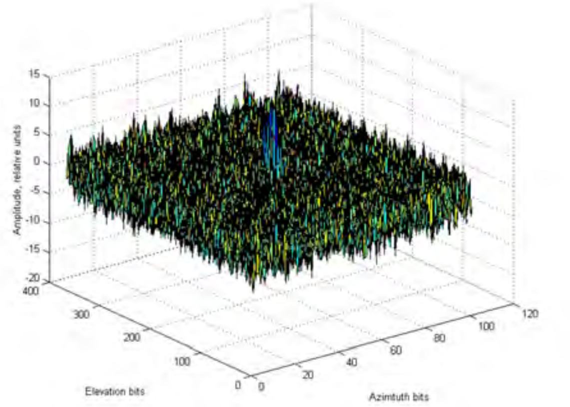
Fig.2 – Antenna radiation pattern

4. The white Gauss noise is added to the signal matrix

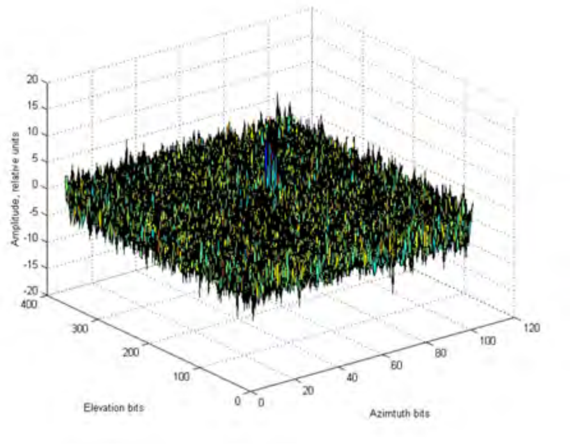
The calculations are made according to the described consistency at the algorithm with the next additional information:

1. *SNR=6dB – signal to noise ratio*
2. *PRF_1=2500Hz, PRF_2=2857Hz – pulse repetition frequencies*
3. *v_r=20m/s – radial target velocity*
4. *N_x=12min^{-1} – antenna revolution*
5. *R=21km – target distance*
6. *N_A=370 – number of azimuth bits*
7. *N_D=64 – number of Doppler bits*
8. *N_R=1024 – number of range bits*

The simulation results are represented at fig.3 and fig.4. The partial time domain 2D matrixs (*I* and *Q* channel) are shown at fig.3a and fig.3b. The shown azimuth bins are limited to 100 bits, which include the target ones. The generated CFAR matrixes, which are estimated by using the sliding window, are shown at fig.4a-c. The Doppler maximum is poorly discernable at the first and the last figures (fig.4a and fig.4c), which are thoroughly contained the noise. When the Hamming window maximum coincades with the target azimuth coordinate then the Doppler peak has the maximum value (fig.4b). Due to these algorithm properties the target azimuth coordinates are established.



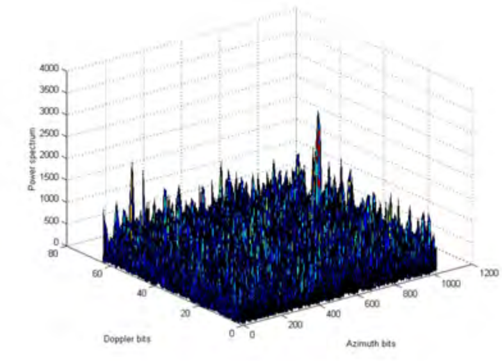
I matrix



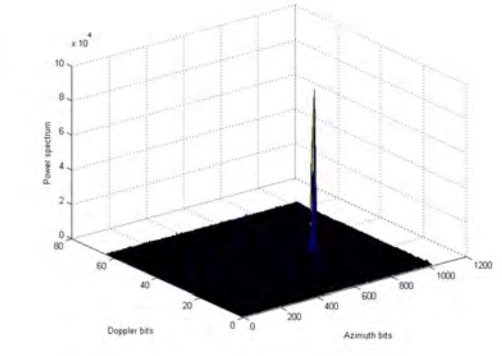
Q matrix

Fig.3 – Time domain 2D matrixes

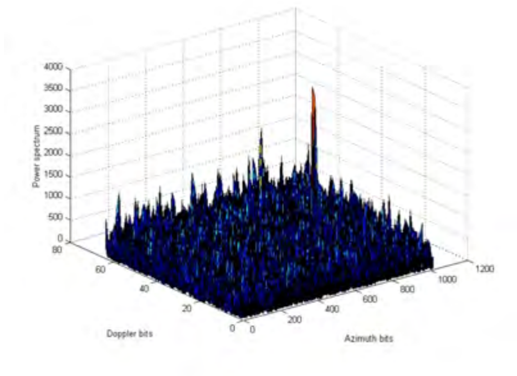
Therefore, the simulations show that the sliding Doppler processing and the proposed spectrum analysis algorithm allow detecting the target azimuth coordinates from the generated CFAR matrix maximums using high speed *FFT* technique to ensure the real-time processing.



(a)



(b)



(c)

Fig.4 – The CFAR matrix

a) 16 bits before the target maximum
b) window coincides with the target maximum
c) 16 bits after the target maximum

IV. Conclusion – The discussed algorithm for coherent Doppler processing using consecutively changed *PRFs* and nonparametric spectral estimation method for the nonuniformly sampled data sequence. The described Doppler processing algorithm provides improved performance for target detection, especially in low *SNR* environments, and is distinguished with an enhanced spatial resolution and great computing efficiency. It is suitable for search Doppler radars with fast frequency changes and a relatively small number of echoes from a target.

V. References

1. Nathanson, Fred E. – "Radar design principles: signal processing and the environment", New York, McGraw-Hill, 1991
2. Edde, Byron – "Radar: principles, technology, applications", N.J., Prentice Hall, c1993
3. Skolnik, M.I.– "Radar handbook", McGrawHill, 1970
4. Schleher, D. Curtis – "MTI and pulse Doppler radar", Boston, Artech House, c1991
5. Barton, David K. – "Radars – Frequency agility and diversity", vol.6, Artech House Inc., London, 1989
6. Armstrong, B.C. – "A comparison of conventional, adaptive and hybrid Doppler processing techniques", Communications and Signal Processing, COMSIG '92, pp: 127 -134
7. Miletiev, R.G.; Arnaudov, R.I. – Spectrum analysis of nonuniformly sampled data, *Proceedings of Technical University - Sofia*, 2004, v.53, No.1