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FAST CORRELATION PROCESSING OF WIDEBAND RADAR SIGNAL

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ABSTRACT

Correlation processing of wideband radar signal is characterized by high computational complexity even if fast spectral transformations (in particular Fourier) are used [1]. In the article is found how computational complexity of such algorithms analytically depends on signal spectrum width and time of its coherent integration. Based on this dependence several ways of further reducing of computational complexity and appropriate algorithms are proposed. Analysis of those algorithms shows that proposed two-stage algorithm is more effective than others are.

Index Terms **-** computational complexity, wideband, radar, correlation, algorithm

1. INTRODUCTION

Wideband continuous signal provides radar with high distance and speed resolution [2]. Digital television and audio broadcasting signals meet this requirement and may be considered as radar signals [3]. Passive radar operating with commercial transmitter (radio, TV, GSM) is now an object of investigation conducted by many scientific groups.

High spectrum width Δf_0 of those signals makes actual the problem of computational complexity of correlation processing. High complexity is determined by large number of time bins $m_r = t_{r\,max}\Delta f_0$, and by large number of signal samples on the interval of its coherent integration $N = q\Delta f_0 T_i$, where $t_{r\,max}$ is maximum time delay of reflected signal, T_i is coherent integration time, q is a ratio of sampling frequency to spectrum width.

The aim of the paper is to develop effective ways of reducing computational complexity of correlation processing of wideband signal, preserving acceptable characteristics of detection and resolution.

2. DETECTION OF WIDEBAND SIGNAL WITH UNKNOWN DOPPLER AND DELAY

Target reflected signal has unknown Doppler and delay. In this case conventional multi-channel correlator is used. To reduce computational complexity fast spectral transformations are applied, in particular fast Fourier transformation (FFT) [1].

Figure 1 shows FFT-based multi-channel correlator. Doppler frequency compensation in surveillance channel is produced in frequency domain by cyclic permutation of spectral coefficients. One position permutation corresponds with frequency shift $1/(N\,t_s)$, where N is FFT order, t_s is sampling period. Shift direction determines sign of frequency correction.

Minimum value of the FFT order depends on coherent integration time T_i and on maximum signal delay in the correlator $t_{r\,max}$:

$$N = (T_i + t_{r\,max})/t_s = q\Delta f_0 (T_i + t_{r\,max}). \quad (1)$$

Practical FFT order may be corrected to nearest 2^n number not lesser than N.

Number of Doppler (speed) bins and delay bins correspondingly is

$$m_v = \Delta F_d (T_i + t_{r\,max}), \quad (2)$$
$$m_r = t_{r\,max}/t_s = q\Delta f_0 t_{r\,max}, \quad (3)$$

where $\Delta F_d = 4V_{t\,max}/\lambda$ is a range of Doppler frequencies, $V_{t\,max}$ is maximum target speed, λ is wavelength.

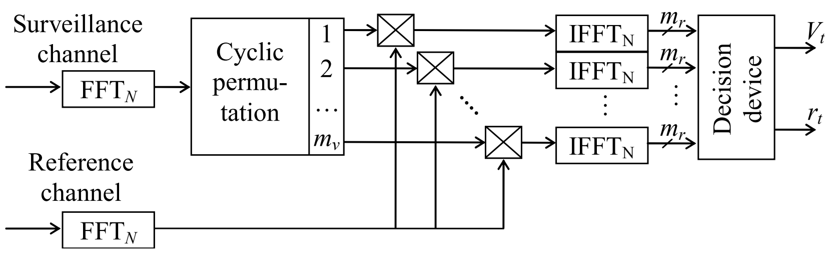

Figure 1. Multi-channel correlation detector with FFT

It is known that N-order FFT required $N\log_2 N$ complex additions and $0.5N\log_2 N$ complex multiplications. Then computational complexity of the algorithm offered on Figure 1 may be estimated as

$$C = 10N\log_2 N + m_v(6N + 5N\log_2 N) \quad (4)$$

and takes $C \approx 3.65\cdot10^9$ arithmetical operations at $\Delta f_0 = 7.61$ MHz (DVB-T signal), $T_i = 40$ ms, $\lambda = 0.5$ m, $t_{r\,max} = 667$ µs (corresponding to detection range 100 km), $V_{t\,max} = 300$ m/s, $q = 1.2$.

Making all this operations during time $T_a = 120$ ms will require DSP with operating speed $S = C/T_a \approx 3\cdot10^{10}$ arithmetical operation per second (ops). For example, Analog Devices processor ADSP-TS203S productivity is about $3\cdot10^9$ FLOPS.

3. COMPUTATIONAL COMPLEXITY REDUCING CONCEPT

Substitution of (1) and (2) into (4) gives:

$$C = 10q\Delta f_0\left(T_i + t_{r\,max}\right)\log_2\left[q\Delta f_0\left(T_i + t_{r\,max}\right)\right] \times\left(1 + 0.5\Delta F_d\left(T_i + t_{r\,max}\right) + \frac{0.6\Delta F_d\left(T_i + t_{r\,max}\right)}{\log_2\left[q\Delta f_0\left(T_i + t_{r\,max}\right)\right]}\right). \quad (5)$$

Usually values $t_{r\,max}$ and ΔF_d can not be varied. Processing complexity may be decreased by using a part of signal spectrum bandwidth, a fragment with width $\Delta f_{0fr} < \Delta f_0$, or by decreasing coherent integration time T_i. From this point of view computational complexity may be presented as function $C(\Delta f_{0fr}, T_i)$. Suitable approximation for this one is

$$\tilde{C}\left(\Delta f_{0fr}, T_i\right) = \Delta f_{0fr}^{z1}\, T_i^{z2}\, c_0, \quad (6)$$

where c_0 is a constant. Mean square error of this approximation is around 1.7% at $z1 = 1.087$ and $z2 = 1.884$. So approximately, we may suppose that

$$\tilde{C}\left(\Delta f_{0fr}, T_i\right) \approx \Delta f_{0fr}\, T_i^{2}\, c_0. \quad (7)$$

Thus, decreasing of T_i is more effective for computational complexity reduction then decreasing of Δf_{0fr}. Also we must take into account influence of mentioned above parameters on time resolution $\Delta t_r = 1/\Delta f_{0fr}$, Doppler resolution $\Delta f_d = 1/T_i$ and on spreading ratio

$$E = T_i\Delta f_{0fr}, \quad (8)$$

which in turn determines acquisition capability of targets.

4. PROCESSING OF SPECTRUM FRAGMENTS OF A SIGNAL

Wideband ($\Delta f_0 = 7.61$ MHz) DTV signal guarantees distance resolution about $\Delta r \approx 20$ m [3]. In many cases, it is redundant. So only a part of signal spectrum with width $\Delta f_{0fr} = p\Delta f_0$ (coefficient $p<1$) can be used. This also results in loss of power by a factor of $1/p$. Let us consider an idea of usage of all signal energy.

At first, we must reject idea that consists in partitioning of entire spectrum into L non-overlapping fragments with width $\Delta f_{0fr} = \Delta f_0/L$, than heterodyning all fragments on the same central frequency with next coherent combining. Such combining is not co-phased in the general case and thus cannot be used.

So only incoherent combining of correlation processing results of separate spectrum fragments is acceptable. This approach results in reducing computational complexity by $L^{z1}/L = L^{z1-1}$ (about 1.3 times if $L = 16$, $z1 = 1.087$) and do not solve computational complexity problem.

5. DIVISION TWO-DIMENTIONAL SIGNAL PROCESSING TASK INTO TWO STEPS

Multi-channel correlator (Figure 1) detects targets in $m_v m_r$ bins. Considerable computational complexity reducing can be obtained with approach based on division two-dimentional (Doppler – delay) target detection task into two one-dimentional consecutive steps. This allows decreasing number of bins to value m_v+m_r. The approach can not be simply applied to processing of complex signals such as OFDM for the following reasons. Doppler frequency of the signal can be determined only after signal spectrum compression during correlation processing, which requires delay time of the signal to be known. On the other hand, signal delay determination required Doppler frequency correction for effective coherent integration.

Proposed two-stage correlation detector (Figure 2) solves mentioned problem.

At the first stage correlation detection of reflected signal in time and Doppler domains is made with rough Doppler resolution due to purposely decreased coherent integration time T_{i1}. However, time resolution is accurate. At this stage multi-channel correlator is used (Figure 1) with N_1-order FFT, where N_1 can be found from (1). Value of T_{i1} is chosen from the compromise between computational complexity (6) and spreading ratio (8). So number of Doppler bins can be reduced to $m_{v1} = 1$. If target detection occurs, estimations of delay time t_r and rough Doppler frequency $f_{d.rough}$ are made. Those estimations are used to tune of the 2nd stage correlator.

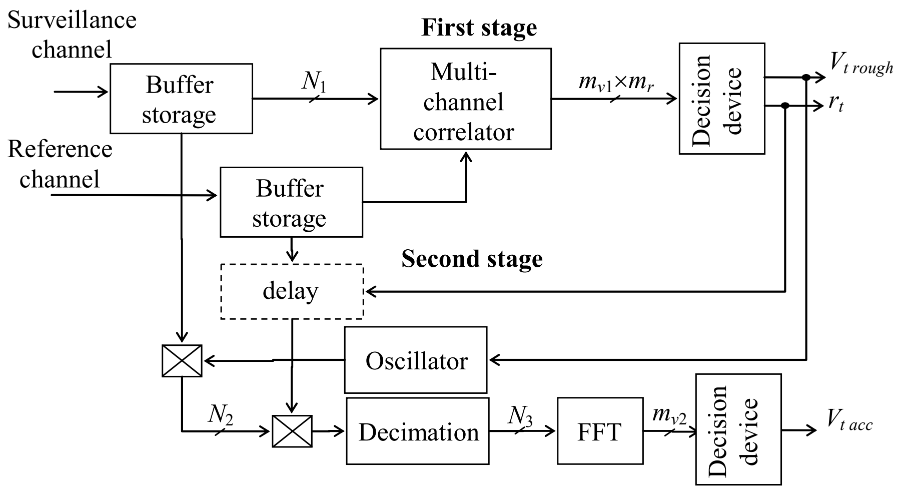

Figure 2. Two-stage correlation detector

At the second stage demodulation and coherent integration of reflected signal are made. A number of Doppler filters can be implemented with help of FFT. At this stage, accurate Doppler frequency $f_{d.acc}$ is determined. Decimation is applied to demodulated (compressed by frequency) signal. It allows reducing computational complexity of the following operations. Buffer storage makes possible to process the same signal realization at both stages. This excludes 2nd-stage correlator tuning error connected to target moving and fluctuations. If several targets are detected at the 1st stage then each of them should be processed at the 2nd stage.

According to (4) computational complexity of the 1st stage and the 2nd stage may be calculated correspondingly as

$$C_1 = 10N_1\log_2 N_1 + m_{v1}(6N_1 + 5N_1\log_2 N_1), \quad (9)$$

$$C_2 = M\,[(12+8u)N_2 - 2N_3 + 5N_3\log_2 N_3], \quad (10)$$

where M is a number of targets detected at the 1st stage; $N_2 = T_{i2}/t_s$ is a number of signal samples; $N_3 = m_{v2}$ is a number of Doppler bins; u is a coefficient depending on length of impulse response of the decimation filter.

6. COMPARATIVE ANALYSIS OF CONSIDERED ALGORITHMS

To understand advantages and disadvantages of this or that algorithm, let us compare them by main parameters given in Table 1: fragment spectrum width (Δf_{0fr}), time of coherent integration (T_i), distance resolution ($\Delta r = c\Delta t_r/2$), target radial speed resolution ($\Delta V = \lambda\Delta f_d/2$), spreading ratio ($E$) and required processor productivity (S). Data in the table was obtained at $r_{t\,max} = 100$ km, $V_{t\,max} = 300$ m/s, $\Delta f_0 = 7.61$ MHz, $\lambda = 0.5$ m, $q = 1.2$, $T_a = 120$ ms, $u = 2$, $M = 3$.

The results let us make a conclusion that two-stage algorithm is more preferable as it has the least computational complexity, provides potential distance resolution and acceptable spreading ratio.

Table 1. Main parameters of algorithms of correlation processing of wideband signal

Type of correlation detector		Δf_{0fr}, kHz	T_i, ms	Δr, m	ΔV, m/s	E, dB	S, $\times 10^9$ ops
Multi-channel FFT-based		7610	40	19.7	6.3	54.8	30
Multi-channel FFT-based with use of $p = 1/16$ spectral fragment		475,6	40	315.4	6.3	42.8	1.51
Multi-channel FFT-based with non-coherent combining of $L = 16$ spectral fragment		475.6	40	315.4	6.3	51.8	24.2
Two-stage with $m_{v1} = 1$	1st stage	7610	0.417	19.7	600	35.0	0.28
	2nd stage	7610	40	19.7	6.3	54.8	
Two-stage with $m_{v1} = 6$	1st stage	7610	2.5	19.7	100	42.8	0.45
	2nd stage	7610	40	19.7	6.3	54.8	

7. CONCLUSIONS

The paper shows that computational complexity of FFT-based multi-channel correlator is a linear function of signal spectrum width and a quadratic function of coherent integration time. Required computational complexity reduction may be achieved by decreasing those parameters. However, this results in deterioration of target resolution and detection.

Consideration of several approaches to computational complexity reduction shows that two of them may be used: a) narrowing signal spectrum width before processing, and b) application of special two-stage algorithm proposed in the paper. At the same time, it is shown that approaches based on partitioning entire spectrum into fragments do not solve computational complexity problem.

Calculations show that better characteristics has two-stage algorithm. It requires three times lesser computational performance compared with processing of 1/16 part of signal spectrum. Besides, two-stage algorithm provides potential distance resolution.

8. REFERENCES

[1] Blahut, R.E., Fast Algorithms for Digital Signal Processing, Addison-Wesley, USA, 1985.

[2] Barton, D., Modern Radar System Analysis, Artech House, 1988.

[3] H.D. Griffiths and C.J. Baker, “Passive coherent location radar systems. Part 1: performance prediction”, Radar, Sonar and Navigation Proceedings, vol. 152, Issue 3, pp. 153–159, 2005.