DETECTION OF MULTIPLE TARGETS BY A MULTISTATIC RADAR

Pavel Bezoušek, Marek Pola[1], Jan Pidanič[2]

Summary: Multistatic radar systems with several transmitters and receivers introduce not only new qualities in area surveillance as well as in hardware minimization but also new problems in signal processing and target detection and tracking. This paper deals with multistatic radar system consisting of several independent bistatic radars processing signals scattered of surrounding objects. The measured data, e.g. time delays and Doppler frequencies at individual radar are therefore not associated with a particular target. An optimal detection method should find the proper associations among a great number of their possible combinations. In this paper a detection method, based on a probability hypothesis density function (PHDF) is described and tested using a mathematical simulation in Matlab.

Key words: Radar, bistatic, multistatic, detection, data association, probability hypothesis density, PHDF.

1. INTRODUCTION

Research and development of active and passive radars for detection of air targets as well as their production has a long tradition in the Czech Republic ([1]). Active radars have their own transmitters, generating the electromagnetic power, needed for the target detection and their position (resp. velocity) estimation [2]. The passive ones receive signals, transmitted by the tracked objects. Contemporary a very high attention is devoted to systems, using so called “transmitters of opportunity” ([3], ([4]). At present a great number of transmitters operating in diverse terrestrial or satellite communication or positioning services cover practically all the Earth by the electromagnetic emission. The electromagnetic waves are scattered by all objects and this effect is used in the modern multistatic systems for object detection and localization.

Classical monostatic radar with transmitter and receiver situated at the same point measures a positions and velocities of external objects (usually called targets). The accuracy of this measurement reached now its limits due to limited antenna aperture dimensions. Multistatic radar systems break this limitation by situating their antennas at large distances, creating super-antenna structures with extremely big apertures.

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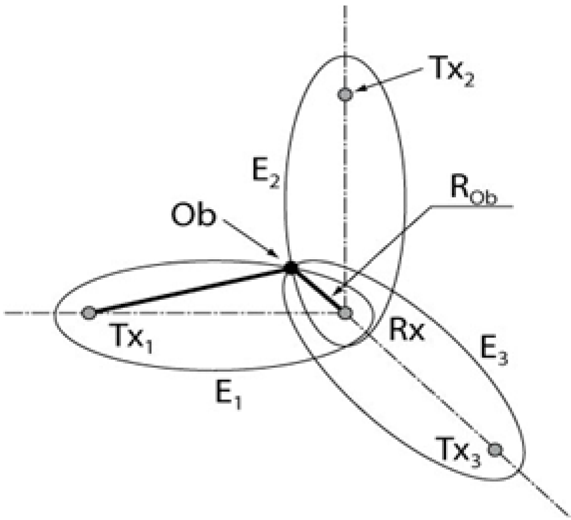

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Fig. 1 - Illustration of multistatic radar system, consisting of one receiver (Rx) and three transmitters (Tx_1, Tx_2, Tx_3). Ob is the scattering object and E_1, E_2, E_3 are ellipses corresponding to constant time delays of signals of individual radars scattered by the object to the receiver.

In the case of monostatic radar all needed position or velocity parameters are evaluated from the measurement of one radar. The ability to detect many targets simultaneously depends only on the radar resolution and no data association problem exists. A multistatic radar system evaluates the target position (resp. velocity) combining measurements of multiple sensors (individual radars). Passive multistatic radar systems receive signals, transmitted by the tracked targets and data association is based principally on differences between signals, generated by separate targets. But those multistatic radar systems, which receive signals reflected or scattered by targets are not able to link each received signal to a particular target and the proper data association procedure could become a very difficult problem particularly in multitarget scenario in a harsh environment.

This paper deals with a multistatic radar system consisting of one receiver and several non-cooperative transmitters ("of opportunity"). Only exact positions of the transmitters are needed and no synchronization or any other forms of cooperation are necessary. Each transmitter – receiver pair (TR) forms a bistatic radar. The receiver receives a direct signal from the transmitter as well as signals scattered of the surrounding objects. . The bistatic radar principles have been described in many publications ([3], ([5], [6]…). From the time delay of the two signals the "elliptic distance" and from the Doppler shift the Doppler velocities are then computed. Combining the data of individual sensors, the position and velocity of each particular target could be estimated. Prior to the targets positions and velocities computation, the links between data, supplied to system from separate bistatic radars should be established. This paper describes a method of individual target detection based on a probability hypothesis density function ([3], [7]) partially optimized to a higher robustness against acquisition collapses. The method is tested in Matlab using simulated bistatic radar data including errors due to noise, data drops and false alarms. It is shown, that the presented method could limit number of false alarms in hard conditions.

2. SIGNAL PROCESSING STEPS IN A MULTISTATIC RADAR SYSTEM (MRS)

2.1 MRS and Bistatic Radar Operation

The MRS under consideration consists of one receiver and several transmitters as is demonstrated in the Fig.1. It is intended for localization and velocity measurement of flying objects in 2D. The transmitter is supposed to broadcast CW signals in specific bands covering the whole area of interest. The receiver collects transmitted signals propagating not only straight on from the transmitters (direct paths), but also scattered by various objects including by objects of our interest (targets). Each transmitter – receiver pair forms bistatic radar. It is supposed, that only the time delay between the direct and scattered signals and the Doppler shift between these signals are measured and no angle information is available at the output of the bistatic radars. In the system shown in the Fig.1 with three transmitters three bistatic radar data sets are available for one scattering object.

Consequently each bistatic radar evaluates the time difference of arrival T_d between the direct path signal and the scattered signal and their (Doppler) frequency shift f_d (due to the object movement). For bistatic radar formed by the receiver R and transmitter T1 on the Fig. 1 it holds:

$$T_d(m,1) = \frac{R(m,1) + R_{Ob}(m) - e(1)}{c}$$
$$f_d(m,1) = -\frac{f(1)}{c}\frac{d}{dt}\left[R(m,1) + R_{Ob}(m)\right] \equiv -f_c(1)\frac{v_d(m,1)}{c} \tag{1}$$

where:

$R(m,1)$, $R_{ob}(m,1)$ are the distances from the m-th object to the transmitter and the receiver correspondingly.

$e(1)$ is the distance between transmitter T1 and the receiver R (eccentricity of the ellipse E1)

c is the light velocity

$f_c(1)$ is the transmitter T1 carrier frequency

$v_d(m,1)$ is the so called Doppler velocity of the m-th object respective to the T1 and R (the time derivative of the sum of distances R(m,1) and $R_{ob}(m)$).

The positions of the receiver and all transmitters are known, therefore the elliptic distance $D(m,1)$ and the Doppler velocity $v_d(m,1)$ could be calculated from the measured data $T_d(m,1)$ and $f_d(m,1)$:

$$D(m,1) = R(m,1) + R_{Ob}(m) = e(1) + cT_d(m,1)$$
$$v_d(m,1) = -c\frac{f_d(m,1)}{f(1)} \tag{2}$$

Quantities $D(m,k)$ and $v_d(m,k)$ are the output data of the k-th bistatic radar corresponding to the m-th target. All objects in the horizontal plane with the same elliptic distance $D(m,k)$ are situated along the ellipse (in 3D at an ellipsoid) with its focuses in positions of the receiver and the k-th transmitter. Each target creates one such an ellipse at each bistatic radar. Theoretically the target position could be found at the intersection of the corresponding ellipses (ellipsoids) of all separate bistatic radars. Therefore there are needed two bistatic radars as minimum for target localization in a horizontal plane and minimally three ones for localization in the 3D space.

The computation of the Doppler velocity $v_d(m,k)$ of the *m*-th object to the *k*-th bistatic radar from the horizontal components $v_x(m)$, $v_y(m)$ of the real object velocity at the specific point $x(m)$, $y(m)$ is rather straightforward:

$$v_d(m,k) = \frac{d}{dt}\left[R(m,k) + R_{Ob}(m)\right] = \frac{dx_0(m)}{dt}\left[\frac{x(m)-x_k}{R(m,k)} + \frac{x(m)-x_R}{R_{Ob}(m)}\right] + \\ + \frac{dy_0(m)}{dt}\left[\frac{y(m)-y_k}{R(m,k)} + \frac{y(m)-y_R}{R_{Ob}(m)}\right] = v_x(m)A(m,k) + v_y(m)B(m,k) \tag{3}$$

$$A(m,k) = \left[\frac{x(m)-x_k}{R(m,k)} + \frac{x(m)-x_R}{R_{Ob}(m)}\right]$$

$$B(m,k) = \left[\frac{y(m)-y_k}{R(m,k)} + \frac{y(m)-y_R}{R_{Ob}(m)}\right]$$

where:

x_k, x_R, y_k, y_R are *x* and *y* coordinates of the *k*-th transmitter and of the Receiver.

Again to be able to compute the two horizontal velocity components of the object velocity, measurements of minimally two Doppler velocities $v_d(m,k)$ of the same object by two different bistatic radars are needed.

2.2 Review of the signal processing in the MRS

On the path from a received signal to the two parameters $D(m,k)$ and $v_d(m,k)$ many processing steps and complicated signal processing methods are used ([3], [8], [9],…) including (see Fig. 2) suppression of the direct signal in the target channel using an adaptive antenna, the direct signal separation of static reflections (clutter) in the reference channel (reference signal cleaning), suppression of the direct signal and static reflections in the target channel using variety of equalization methods, correlation of the two channels to generate their cross-ambiguity function and finally the extraction of $T_d(m,k)$ and $f_d(m,k)$. After computing the $D(m,k)$ and $v_d(m,k)$ parameters, the bistatic radar data of all radar sensors are collected and detection of individual targets is started. The detection method is described in details in the chapter 3.

These steps of the signal processing are repeated in the time measurement period T_{op}, determined mainly by the integration period T_i (typically in the range 0.1 - 1 s). The integration period should provide a sufficiently good system resolution in the Doppler frequency shift to enable the necessary filtering of moving objects from the clutter. The further step after the target detection is target tracking and plotting their trajectories. The aim of this stage is to provide reliable information on all the real targets present at the area of interest cleaned of noise and false targets. Many different methods are used including various modifications of Kalman and particle filters (see [7], [10]) to perform this task.

3. TARGET PRE-DETECTION METHOD

3.1 Input and output consequences

As was stated above the bistatic radars measurements consist of elliptic distances $D(m,k)$ and the Doppler velocities $v_d(m,k)$, where in the ideal case of no target miss and no false alarm: $m = 1,\dots M$, $k = 1,.., K$ and M is a number of all observed targets and K is a number of transmitters (bistatic radars). These data represent the input of the detection procedure.

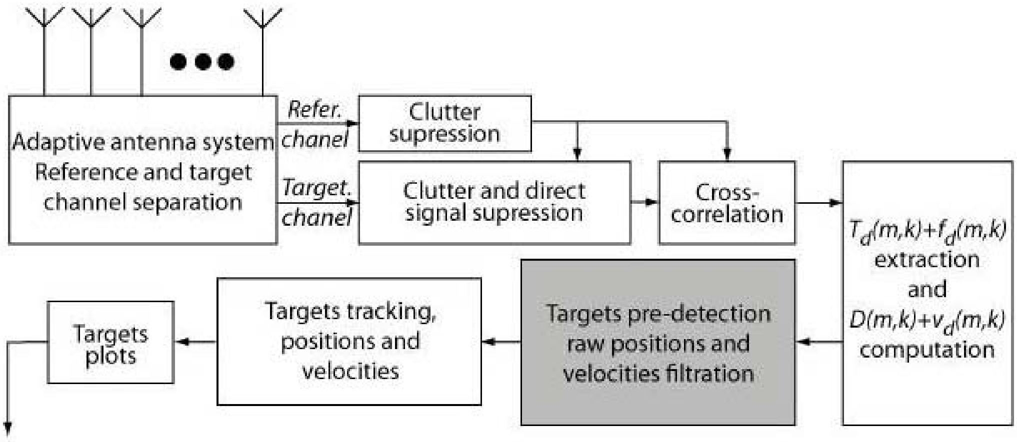

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Fig. 2 The basic signal processing stages in MRS. The section discussed in this paper is highlighted.

In usual conditions the bistatic radars suffer from a very low amplitude of reflections of the observed targets (aircrafts, air-balls and air-ships, ultralights, missiles, e.t.c.) in comparison to amplitudes of other reflections (clutter) and noise. The probability of the needed data acquisition at the bistatic radar level is therefore significantly reduced and on the other hand false alarm probability can not be ignored. (i.e. there is a low probability of detection and a significant probability of false alarm). That is why the number M of the measured data (pairs of $D(m,k)$ and $v_d(m,k)$) at individual bistatic radar are not the same. The number of supplied data from the k-th bistatic radar we thus denote by M_k. As was mentioned above the data are supplied repetitively after the interval T_{op}. The number M_k then fluctuates not only from one bistatic radar to another but also in time. In addition as the operations of the bistatic radars are independent, the succession of the measurements, described by the index m should not be necessary the same in all radars. Therefore, the measurement results at individual radars are not associated to each other and suitable method of association is needed.

In a typical case these measured data are used as the measurement data vector directly in the target tracking. The data association thus takes place in the tracking phase. But the raw measured data suffer from a measurement miss and from false measurements not corresponding to any real target. If only some measurement misses in one measured data set, the tracking processor substitutes it by an extrapolation of the previous ones. On the other hand if a false measurement occur a new trajectory is established and innovated for several measurement periods. This is a big complication of the tracking process consuming much of the computation power and memory.

The role of the pre-detection phase is to associate the measurement data of the individual radars and to suppress false measurements. In some cases it could also overpass the missed measurements. It may highly simplify the target tracking. In addition the pre-detection constitutes a necessary phase during initialization of the tracking process.

3.2 The pre-detection method description

In modern systems the radars could supply not only the elliptic distances and the Doppler velocities but also estimation of standard deviations σ_D and σ_V of these measurements. (The method of the standard deviations estimation is described at the paragraph 4.2.) We will assume that the *k*-th radar supply its measurement as a set of four parameters, corresponding to one target, which for a better handling in the consequent calculations we rearrange forming a complex measured data matrix *d*(*k*):

$$d(k) \equiv \begin{Vmatrix} D(1,k) & v_d(1,k) & \sigma_D(1,k) & \sigma_v(1,k) \\ D(2,k) & v_d(2,k) & \sigma_D(2,k) & \sigma_v(2,k) \\ \vdots & \vdots & \vdots & \vdots \\ D(M_k,k) & v_d(M_k,k) & \sigma_D(M_k,k) & \sigma_v(M_k,k) \end{Vmatrix} \tag{4}$$

where the individual rows of this matrix are results of separate measurements ($m = 1,.., M_k$) at the *k*-th bistatic radar. We suppose that no correlation exists between measurements at two separate radars. The measurement of the elliptic distance and the Doppler velocity in one radar are also assumed to be uncorrelated. (These two quantities are measured by evaluating the position of the cross-ambiguity function main peak in the orthogonal time delay and Doppler shift coordinates).

At first we describe the method in the ideal situation, when no missed or false measurement occurs. Then all the $M_k = M$ - the number of real targets.

Let be: $x(m), y(m), v_x(m), v_y(m)$ the targets horizontal positions and velocities. Then the undistorted (by the measurement noise) data $D_0(m,k)$ and $v_{d0}(m,k)$ could be computed (using partially Eq.(1) and (3)) by the following formula:

$$
\begin{aligned}
&D_0(m,k) = R(m,k) + R_{Ob}(m) \\
&v_{d0}(m,k) = v_x(m)A(m,k) + v_y(m)B(m,k) \\
&R(m,k) = \sqrt{\left[x(m) - x_k\right]^2 + \left[y(m) - y_k\right]^2} \\
&R_{Ob}(m) = \sqrt{\left[x(m) - x_R\right]^2 + \left[y(m) - y_R\right]^2}
\end{aligned}
\tag{5}
$$

The measured quantities are subject of an uncorrelated additive noise. According to the Probability Hypothesis Density (PHD) – see [7] or [10] we may choose Gaussian probability density functions (pdf), with standard deviations $\sigma_D(m,k)$ and $\sigma_V(m,k)$ correspondingly, for the representation of the PHD Functions (PHDF) of the measured values $D(m,k)$ and $v_d(m,k)$:

$$
\begin{aligned}
&P_D(m,k) = C_D.\exp\left\{-\frac{\left[D(m,k) - D_0(m,k)\right]^2}{2\sigma_D^2(m,k)}\right\} \\
&P_v(m,k) = C_v.\exp\left\{-\frac{\left[v_d(m,k) - v_{d0}(m,k)\right]^2}{2\sigma_v^2(m,k)}\right\}
\end{aligned}
\tag{6}
$$

where:
$P_D(m,k)$ .. is a PHDF of measurement of the elliptic distance $D(m,k)$ of the m-th target at the k-th radar
$P_v(m,k)$ .. is a PHDF of measurement of the Doppler velocity $v_d(m,k)$ of the m-th target at the k-th radar.
C_D, C_v …are constants.

The basic idea of PHDF is to express likelihood of the particular target position $x(m)$, $y(m)$ and the velocity $v_x(m)$, $v_y(m)$ in the case of the measured data $D(m,k)$ and $v_d(m,k)$. In fact the measurement noise consists of the receiver noise (with Gaussian pdf) and of sidelobes of the suppressed direct path signal and clutter residues (with unknown distribution). We will construct the PHDF using Gaussian distributions with the same positions of maxima as the true pdfs and with real standard deviations of measured quantities adopting also the same procedures of evaluation as for a the true pdf .

The PHDF of the measurement of elliptical distances $P_D(m,k)$ is a function of the hypothetical position of the m-th target. But $P_v(m,k)$ is function not only of the position but also of the velocity of the target (see Eq. (5)). To find the PHDF as a function of only the positions of targets the elimination of target velocity is needed. It was mentioned previously, that minimally two radars should operate in the MRS. But in the case of $K = 2$ there are two linear equation for two unknown velocity components v_x and v_y. Each pair of the measured Doppler velocities could be transformed at each point to some v_x and v_y and hence the velocity measurement in this case has no added value for the data association and errors suppression. That is why we will suppose that the MRS consists of $K > 2$ bistatic radars.

Than we have *K* (>2) linear equation for only two velocity components which could be solved using the least mean square method:
The linear equation:

$$\mathbf{V_d}(m) = \mathbf{A}(m) \cdot \mathbf{V}(m) \tag{7}$$

Where:

$$\mathbf{V}(m) \equiv \begin{vmatrix} v_x(m) \\ v_y(m) \end{vmatrix}$$

$$\mathbf{A}(m) \equiv \left\| A_{ki}(m) \right\|, \quad k = 1,..,K, \quad i = 1,2$$

$$\mathbf{V_d}(m) \equiv \begin{vmatrix} v_{d0}(m,1) \\ v_{d0}(m,2) \\ \vdots \\ v_{d0}(m,K) \end{vmatrix}, \quad \mathbf{\Delta}(m) \equiv \begin{vmatrix} \delta(m,1) \\ \delta(m,2) \\ \vdots \\ \delta(m,K) \end{vmatrix}$$

$$A_{k1}(m) = \left[\frac{x(m) - x_k}{R(m,k)} + \frac{x(m) - x_R}{R_{Ob}(m)} \right]$$

$$A_{k2}(m) = \left[\frac{y(m) - y_k}{R(m,k)} + \frac{y(m) - y_R}{R_{Ob}(m)} \right]$$

The solution with the corresponding Doppler velocity measurement errors are then:

$$\mathbf{V}(m) = \left(\mathbf{A}^H(m) \cdot \mathbf{A}(m) \right)^{-1} \cdot \mathbf{A}^H(m) \cdot \mathbf{V_d}(m) \tag{8}$$

$$\mathbf{\Delta}(m) = \left[\mathbf{A}(m) \cdot \left(\mathbf{A}^H(m) \cdot \mathbf{A}(m) \right)^{-1} \cdot \mathbf{A}^H(m) - \mathbf{I} \right] \cdot \mathbf{V_d}(m)$$

where:

$\mathbf{V_d}(m)$ is a vector of measured Doppler velocities of the *m*-th target
$\mathbf{V}(m)$ is a vector of the horizontal velocity of the *m*-th target
$\mathbf{A}(m)$ is a system matrix
$\Delta(m)$ is a vector of errors of the Doppler velocity measurement at the *m*-th target
$\mathbf{A^H}$ is a complex transpose of **A**
I is a unity matrix.

The second equation of (8) gives measurement errors of the Doppler velocities of the *m*-th target at all radars, depending only on hypothetic target position $x(m)$, $y(m)$ and on measured data. The individual components of this vector could then be substituted in the Eq. (6) as $v_d(m,k) - v_{d0}(m,k)$.

The measurements of elliptic distances and Doppler velocities in the same radar are assumed to be uncorrelated as well as the measurements at distinct radars. Therefore the pdf of the measurements of these data is a product of the individual pdfs. The same procedure should be used in computation of the PHDF:

$$P_d(m_1, m_2, ..m_K) = C_d \exp(-S)$$
$$S = \sum_{k=1}^{K} \frac{\left[D(m_k,k) - D_0(m_k,k)\right]^2}{2\sigma_D^2(m_k,k)} + \sum_{k=1}^{K} \frac{\left[v_d(m_k,k) - v_{d0}(m_k,k)\right]^2}{2\sigma_v^2(m_k,k)} \quad (9)$$

where:

$P_d(m_1,m_2,\dots,m_k)$ is a PHDF of the measurement of m_1-th data at the 1st radar, and of m_2-th data at the 2nd radar, and of …. m_K-th data at the K-th radar.

C_d is a constant.

The number of possible combinations of radar measurements $\{m_k\}_{k = 1\dots K}$ is $N = M^K$. For inst. if $M = 5$, $K = 4$, $N = 625$. Each target generates one ellipse at one radar. Every two ellipses of different radars have maximally four intersections. It means that in the above mentioned situation the ellipses could have as much as 2500 intersections. If K = 2, there is no possibility to distinguish between the intersections of two ellipses using the presented method without use of further classification methods (angle measurement e.t.c.).

The cumulative pdf of all possible combination equals the sum of pdf of all combinations. The same is true for the PHDF:

$$P_C = \sum_{all\ \{m_k\}} P_d(m_1, m_2, ..m_K) \quad (10)$$

where: P_C is a cumulative PHDF of all the possible combinations of measurements.

The PHDF $P_D(m,k)$ of the elliptical distances has its maxima along the ellipse $D(m,k) = konst = D_0(m,k)$ – the measured elliptical distance. In product with other $P_D(m,k)$ the maxima will peaked in vicinity of the ellipses intersections, indicating the nearby intersections. In the product with PHDF of the Doppler velocities only those maxima are supported where the Doppler velocity errors $|\Delta(m)|$ are low. In the cumulative PHDF only several $P_d(m_1,m_2,\dots,m_k)$ are significant. The maximum value of the $P_d(..)$ peaks may be equal 1. To find the correct association of measurements of separate radars only P_d with their peak amplitudes above a certain reference level are selected. These P_d represent the correct combinations of measurement corresponding to the real targets. The question of the reference level selection will be discussed in the paragraph 4.2.

Now we will discuss the situations when some measurement is missed or when some false measurements are supplied. In the case of the false measurements there is a high probability, that no P_d, comprising this measurement will be selected due to small peaks. In the case, of a missing measurement the target completely miss during the described procedure. If the number of radars $K > 3$ it is possible to recover this target eliminating all the measurements of one of the radars ($k = k_0$) by removing $P_D(m,k_0)$ and $P_v(m,k_0)$ from the described detection procedure and reducing the system to the order K-1. This method can not be used in the case of $K = 3$, because the system with $K = 2$ does not work in the case of multiple targets (as discussed above). The method how to reveal the radar where is the measurement missing will be shown in the paragraph 4.2. The just described methods of elimination of the acquisition phase faults is not perfect and in some cases the errors penetrate into the next processing phase and should be suppressed there. But each reduction of the measurement errors in the stage of pre-detection is of very high value for the tracking phase.

4. SIMULATION AND INVESTIGATION

4.1 Radar data generation

To permit simulation and testing of the pre-detection method the reliable measured data should be obtained. The radar data generator running in Matlab, generates matrices $d(k)$, k = 1, …, K, defined by the Eq. (4).

The input data are:

- Dimensions of the area of interest and number of points along the x axe: Lx, Ly, N
- Positions of the receiver and transm.: $x_R, y_R, x(k), y(k)$
- Number of real targets, of missed and false measurements: M, M_M, M_F
- Signal to Noise Ratio (target at the defined position R_r) and Signal to Clutter Ratio: *SNR0, SCR*
- Integration period in the signal correlation phase: T_i
- Bandwidths of the transmitted signals: $B(k)$

The program starts with generating positions and velocities of M targets, randomly distributed in the area of interest and in the prescribed velocity limits. Then their exact elliptic distances and Doppler velocities are computed according to Eq. (5). In the further step standard deviations σ_D and σ_v are estimated. Standard deviation of these measured quantities could be expressed by the following equations ([11]):

$$\sigma_D = \frac{c}{B.\kappa\sqrt{2.SIR}}, \quad \sigma_v = \frac{c}{T_i f_0.\kappa\sqrt{2.SIR}}$$
$$\frac{1}{SIR} = \frac{1}{SNR} + \frac{1}{SCR} \tag{11}$$

where: B is a signal bandwidth

SIR is a Signal to Interference Ratio

κ is a constant, characteristic for the measurement method, typically $\kappa = 1 - 2$

The SNR of the signal of the k-th transmitter, scattered by the m-th target could be expressed as follows:

$$SNR(m,k) = \frac{SNR0.R_r^4}{R^2(m,k)R_{Ob}^2(m)} \tag{12}$$

where: R_r is a reference distance (input data).

The measurement errors $\delta_D(m,k)$ and $\delta_V(m,k)$ of the elliptic distances and the Doppler velocities are generated with a Gaussian pdf and with the computed standard deviation using random generator. The output data are then sum of the exact data and the relevant error.
To simulate data miss or false data generation, the data $D(M,K)$ and $v_d(M,K)$ are substituted by randomly generated ones.

4.2 Testing of pre-detection method

The pre-detection method runs in Matlab according to the Eq. (6), (7), (8), (9) and (10) with only slight modifications, facilitating a higher speed of the computation. Finally automatic extraction of the target positions and their velocities is attached.

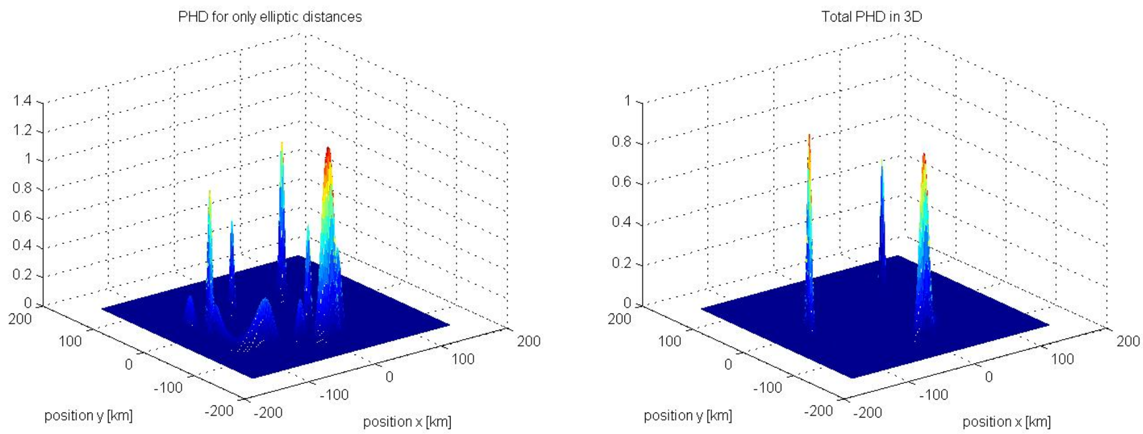

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Fig.3. Comparison of PHDs of the methods: a) comprising the velocity condition (left) and b) using only the elliptic distances (right). K = 3, M = 3. The targets positions (x, y) [km]: (0, -100); (40, 40); (-100,0).

At first we tested the effect of application of the Doppler velocity condition on the results of the data association. By the application of the Doppler velocity condition we mean the incorporation of P_v (the velocity PHDF) in the cumulative probability P_C. In the Fig. 3. the cumulative PHDF is displayed for the same situation (M=3, K=3) first with application of the velocity condition and then the P_v is removed and only elliptic distances are taken into account. The maxima of the P_C show the positions of the real targets. We may see that with application of the velocity condition (Fig. 3-left) the plot clearly shows the target positions. In the other case (Fig. 3-right) there are much more peaks of PHDF and the positions of the true targets are hard to select. The probabilities P_D reflect only proximity of the ellipses intersections with no attention to the source of the ellipses and therefore they could not facilitate the correct data association. It is clear, that the velocity condition is necessary in spite of that it highly complicates the computation.

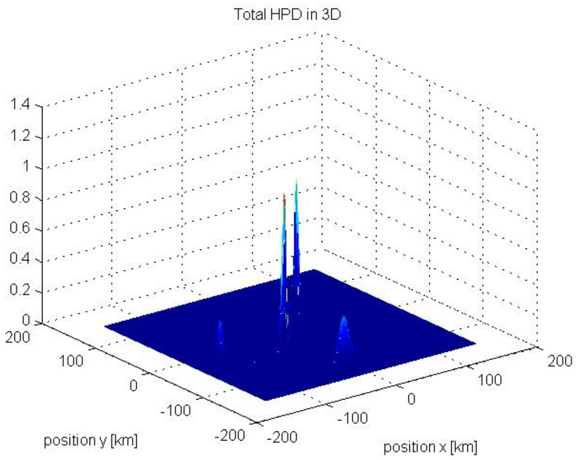

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Fig. 4. PHD of four targets in positions (x, y) [km]: (0, -100); (40, 40); (-100, 0); (-40, -40). Number of transmitters K = 3.

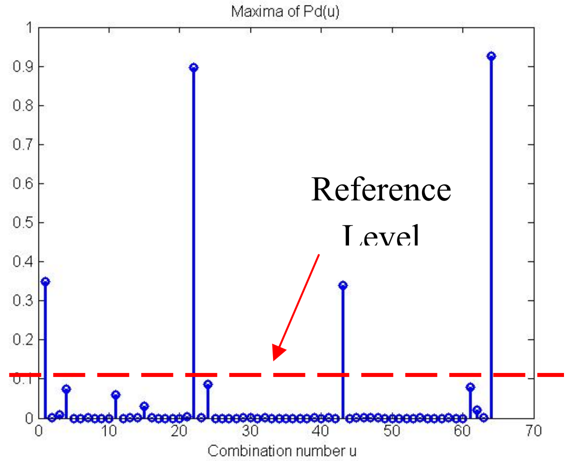

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Fig.5. Maxima of the $P_d(m_1,m_2,m_3)$. Four real targets with combination numbers: u = 1 (1,1,1), u = 22 (2,2,2), u = 43 (3,3,3) and u = 64 (4,4,4)

Tab.1. Differences of the positions and velocities between the detected and the real targets. Results of 10 runs with the same targets and randomized measurement data

Target No.	K	σpos [km]		σvel [m/s]	
		x	y	vx	vy
1	3	0.56	2.67	10.64	9.28
	4	0.50	2.50	9.5	7.88
2	3	2.14	1.14	0.40	12.81
	4	1.96	0.98	0.40	11.70
3	3	0.33	0.88	7.15	5.71
	4	0.30	0.78	6.45	5.10
4	3	0.87	0.13	11.93	5.84
	4	-	-	-	-
Total	3	**1.58**		**8.80**	
	4	**1.41**		**7.71**	

Resource: Author

The reference level for target detection should be adjusted at the level of 0.1 – 0.2. It is clear, that some uncertainty still exists resulting in a nonzero probability of a target miss or in generation of false targets.

The effect of imperfect data has been studied on the systems with three and four transmitters. In both cases one of the correct measurements has been substituted by an erroneous one. The results are presented in the Tab. 2. We may see that no false target is created but without adaption of the described method one target is overlooked.

To defeat this drawback the data measured by the *k*-th radar were omitted alternating *k* from 1 to *K*. The results were compared with the results of the full data set. If there is a combination of *K*-1 transmitters measurement presenting more targets, there should be an error in the data removed. Finally we may correctly evaluate all real targets parameters. The results, displayed in the Tab. 2 confirms this concept for K = 4. In the case of K = 3 the reduced system is not effective in the multitarget case and consequently the target loss cannot be eliminated in this case.

Tab.2. Pre-detection results in the case of imperfect data (measured data of the target No.3 at the radar $k = K$ are erroneous).

Target No.	System structure	σ_{pos} [km]	σ_{vel} [m/s]
1	Full system K=3	2.72	14.11
	Reduced sys. K=2	Functionless	
1	Full system K=4	2.55	12.34
	Reduced sys. K=3	2.72	14.11
2	Full system K=3	2.42	12.81
	Reduced sys. K=2	Functionless	
2	Full system K=4	2.19	11.70
	Reduced sys. K=3	2.42	12.81
3	Full system K=3	Target loss	
	Reduced sys. K=2	Functionless	
3	Full system K=4	Target loss	
	Reduced sys. K=3	0.94	9.15

Resource: Author

5. CONCLUSION

This paper the concept of probability hypothesis density of detection and pre-detection of targets in multistatic radar is presented and tested in a multitarget scenario. The pre-detection phase is inserted in the processing chain between the measured data collection of separate radars and the target tracking to associate radar data of individual radars and to suppress the effects of false measurements or of real target measurement loss. The method is tested on simulated radar data, supplied by the generator program.

The test results show, that the method is efficient in radar data association and in correct estimation of the targets positions and velocities. In the case of erroneous data the adapted method may suppress the effect of data imperfection in some cases. This may significantly reduce computational power and memory in the succeeding target tracking stage of the signal processing.

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