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Fusion of Multiple Estimation of Emitter Positions

Ivan Pokrajac[1]
Predag Okiljević[1]
Desimir Vučić[2]

Multisensor data fusion is very important in defence systems. Data fusion can be used to integrate individual sensor data into the common operational picture of the battlefield. However, there is still a possibility to improve the quality of individual sensors. In this paper, we investigate a possibility to improve the quality of individual sensor data from Electronic Warfare (EW) systems. Some novel methods and techniques for estimating emitter positions are compared in this paper, such as the Discrete Probability Density (DPD) method, the fusion of multiple bearing lines and the mean-square distance algorithm. These methods are examined in order to be used in the process of forming the electronic order of battle (EOB). A procedure for EOB forming based on combining estimated emitter positions is proposed in this work.

Key words: **data fusion, electronic warfare, confidence ellipsis, radiolocation, emitter.**

Introduction

DETERMINATION of emitter positions (emitter geo-locations) has various applications in both civil and defense oriented fields. In the defense application, the determination of emitter positions is very important in electronic warfare (EW) systems and systems for gathering intelligence data such as the COMINT (Communication Intelligence) system at a tactical level. Electronic support (ES), as a part of EW, provides near-real-time information which can be developed into the Electronic Order of Battle (EOB) for situational awareness, or can be fused with other intelligence data from the ISR (Intelligence, Surveillance and Reconnaissance) system in order to develop a common operational picture of the battlefield. Usually, if there are only data from ES systems, gathered by interception of radio emitters in the area of interest (AOI), instead of the EOB, this picture is often named the Communication Order of Battle (COB). The first step in forming the COB is the interception of radio emitters and the determination of their positions.

Generally, the passive methods for determining emitter positions are divided into two major groups: one-step positioning techniques (centralized processing) and two-step positioning techniques (decentralized processing). One-step techniques or direct methods are based on direct position determination. Acquired samples from all sensors are sent to a common central unit which jointly processes the received data and estimates the emitter location in a single step. Two-step positioning techniques or indirect methods are based on the estimation of a specified parameter such as the angle of arrival (AOA) or the time of arrival (TOA) at each sensor. In the second step, the estimated parameters are sent to the central sensor in order to determine the emitter location.

In this paper, we consider two-step positioning methods based on the estimation of the AOA and the triangulation of bearings. In order to overcome a general problem in the two-step positioning techniques - how to ensure that parameters estimated at different sensors correspond to the same radio emitter - synchronization between all sensors in the network must be achieved. In addition, it is supposed that there is some pre-processing (signal pre-classification) at each sensor in the network. During the pre-classification each sensor detects and classifies emissions.

For the emitter position determination, three methods have been compared in this paper. The Discrete Probability Density (DPD) method proposed in [1] is used to combine sensor measurements taken from different locations for the emitter position determination. This method is based on the assumption that the sensor measurement can be modeled by some probability density function over the range of possible values. The fusion of multiple bearing lines method proposed in [2] is based on the aggregation of multiple fixes obtained through the fusion of two bearing lines (AOAs). The mean-squared distance algorithm is based on minimizing the square of the miss distance of the best point estimate from the measured lines of the position [3]. These three methods are compared with the Cramer-Rao low boundary (CRLB).

Generally, the COB has to be formed in a selected observation interval T and a frequency band of interest. Usually, there are more determined emitter positions that arise from the same emitter. In order to provide only one and improved estimation of the emitter position, it is necessary to combine (fuse) the estimated emitter positions and their uncertainties. The uncertainties of the estimated emitter positions are expressed in the form of error ellipses centered upon the estimated positions. The common way to represent the error estimate is to determine a covariance matrix for calculating the Elliptical Error Probable (EEP). In this paper we investigate which of three methods for the emitter position determination exhibits more accurate estimation of a

[1] Military Technical Institute, Ratka Resanovića 1, 11132 Belgrade, SERBIA
[2] Union University, School of Computing, Knez Mihajlova 6, 11000 Belgrade, SERBIA

new emitter position after fusing multiple emitter positions and their EEPs.

This work consists of four parts. The introduction is given in Section I. The basic theory of methods for the determination of emitter positions is presented in Section II with some simulation results. Section III describes how to fuse the determined emitter positions that arise from the same emitter with some simulation results. The conclusion is given in Section IV.

Determination of emitter locations

A) Discrete Probability Density (DPD) method

The DPD method is based on the assumption that the sensor measurement of a given parameter, in this case AOA, can be modeled by some probability density function (PDF) over the range of possible values. These PDFs may be represented by various distributions such as Gaussian distribution or von Mises PDF [4]. The DPD method combines the probability density distribution of measurements directly by sampling each PDF at common intervals and calculating the joint product over the space. The DPD method is applied to determine the emitter position by projecting the measurement PDF from each sensor onto a common grid of sample points. This requires that some transform function exists in order to map the measured parameter into the 2-dimensional space (2-dimensional grid in X, Y of the Cartesian coordinate system). The angular transform function between the sensor location (x_i, y_i) and a grid point (x, y) is simply expressed as $\theta_i(x,y) = \arctan((y-y_i)/(x-x_i))$.

Angular measurements (AOA) can be represented by von Mises PDF [4]:

$$f(\theta) = \frac{1}{2\pi I_0(k)} \exp(k \cdot \cos(\theta - \phi)), 0 \le \theta < 2\pi \quad (1)$$

where φ is the mean of the variable θ, k is analogous to an inverse variance, $k=1/\sigma^2$, and $I_0(k)$ is a modified Bessel function of the first kind and zero order. The two-dimensional AOA DPD array can be represented by:

$$F_{XY}(n,m) = f(\theta_i(X(n),Y(m))), \quad n = 1...N, m = 1...M \quad (2)$$

where F_{XY} is the AOA DPD array of size $N \times M$. For multiple DOA measurements, the joint DPD array is calculated over a common $N \times M$ grid:

$$P'_{XY}(n,m) = \prod_{s=1}^{S} F_{XY}(s,n,m), n = 1...N, m = 1...M \quad (3)$$

where S is the total number of sensors. The joint DPD array is normalized by $C = \sum_{n=1}^{N}\sum_{m=1}^{M} P'_{XY}(n,m)$ and can be expressed by:

$$P_{XY}(n,m) = \frac{1}{C} P'_{XY}(n,m) \quad (4)$$

where $P_{XY}(n,m)$ representing the emitter location.

The two-dimensional determination of the emitter location (x_T, y_T) is determined by first taking the Probability Mass Function (PMF) of $P_{XY}(n,m)$:

$$PMF_X(n) = \sum_{m=1}^{M} P_{XY}(n,m), n = 1...N$$
$$PMF_Y(m) = \sum_{n=1}^{N} P_{XY}(n,m), m = 1...M \quad (5)$$

The estimated value is determined from the indices n and m weighted by PMF:

$$\hat{n} = \sum_{n=1}^{N} nPMF_X(n)$$
$$\hat{m} = \sum_{m=1}^{M} mPMF_Y(m) \quad (6)$$

This is translated back into the X-Y space within the range [X_a, X_b] and [Y_a, Y_b] sampled at the intervals Δx and Δy:

$$x_T = \Delta x \hat{n} + X_a$$
$$y_T = \Delta y \hat{m} + Y_a \quad (7)$$

In order to estimate the position error (error ellipses) of the DPD method, the covariance matrix should be determined. The location error estimate is determined by the variances and covariance of the joint DPD array about the indices of the estimated emitter position [1]:

$$\sigma_X^2 = \Delta x^2 \cdot \sum_{n=1}^{N} PMF_X(n) \cdot \left(n - \hat{n}\right)^2,$$
$$\sigma_Y^2 = \Delta y^2 \cdot \sum_{m=1}^{M} PMF_Y(m) \cdot \left(m - \hat{m}\right)^2, \quad (8)$$
$$\rho_{XY} = \Delta x \cdot \Delta y \cdot \sum_{n=1}^{N}\sum_{m=1}^{M} P_{XY}(n,m) \cdot \left(n - \hat{n}\right) \cdot \left(m - \hat{m}\right)$$

An example of the DPD determination of the emitter position is shown in Fig.1. It is assumed that the AOI is a 500×500 point grid with a 50 meters sampling resolution (25km x 25km). There are three Direction Finders (DF) at positions (2.5 km, 1.5 km), (8 km, 1.5 km) and (14 km, 1.5 km), respectively, inside the AOI. It is supposed that all estimated AOAs are represented by von Miss PDF with standard deviation σ=3°. The true emitter position is (7.5 km, 10 km).

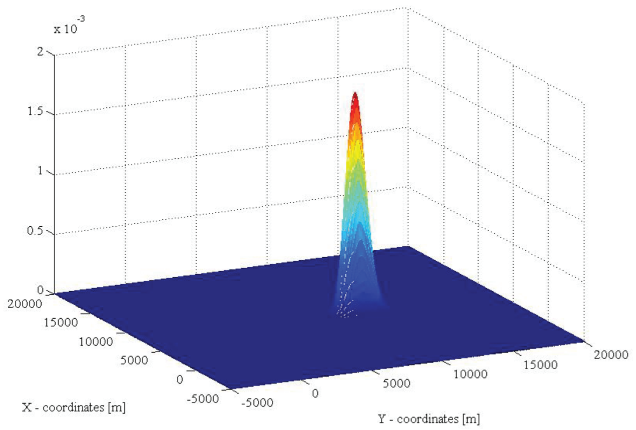


Figure 1. Determination of the emitter position using the DPD method

B) Fusion of multiple bearing lines method

Suppose that there are three bearing lines with the parameters set $B_i(x_i, y_i, \varphi_i, \sigma_i)$, ($i$=1, 2, 3) where x_i and y_i represent the coordinates of the i-th sensor, φ_i is the estimated DOA from the i-th sensor and σ_i is the standard deviation (RMSE). The fused fix from these three bearing lines can be represented by EEP with the parameter set $E(x_T, y_T, a, b, \beta)$ and it could be estimated by optimizing the objective function J [2] given by:

$$J = \frac{1}{2}\left(\frac{(\theta_1-\phi_1)^2}{\sigma_1^2}+\frac{(\theta_2-\phi_2)^2}{\sigma_2^2}+\frac{(\theta_3-\phi_3)^2}{\sigma_3^2}\right)^2 \quad (9)$$

where θ_i is the bearing line from the i-th sensor to the center of the EEP. This is a non-linear least square problem, and it is very unlikely to find an analytic solution due to the difficulty of nonlinearity. A numeric solution such as the one presented in [5] and the approximate analytic solution presented in [6] have been developed. Paper [2] proposes another approximate analytic solution using formulation of two bearing lines. In this case, for each pair of bearing lines it is possible to determine a fix and the EEP (blue ellipses in Fig.2) and then fuse all $S(S\text{-}1)/2$ fixes to obtain the emitter position and its EEP (a red ellipse in Fig.2).

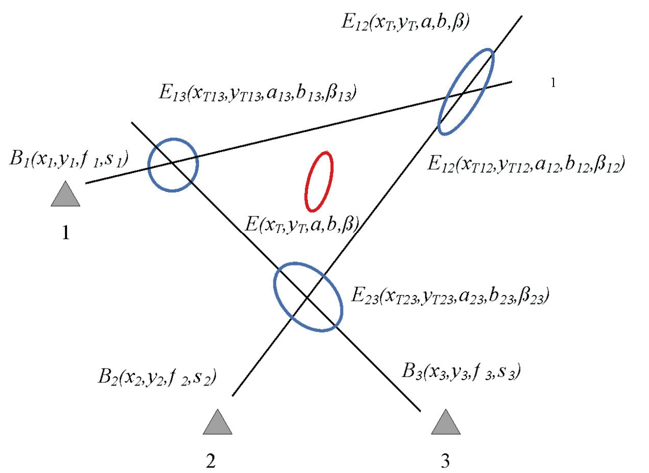


Figure 2. Fusion of three bearing lines through three estimated fixes obtained from three pairs of AOA

Referring to Fig.2, the interception point (x_{T12}, y_{T12}) obtained using the first two bearing lines characterized by the parameters $B_1(x_1, y_1, \varphi_1, \sigma_1)$ and $B_2(x_2, y_2, \varphi_2, \sigma_2)$ could be computed as:

$$\begin{bmatrix} x_{T12} \\ y_{T12} \end{bmatrix} = \left\{\sum_{j=1}^{2}\begin{bmatrix} \cos^2\phi_j & -\sin\phi_j\cos\phi_j \\ -\sin\phi_j\cos\phi_j & \sin^2\phi_j \end{bmatrix}\right\}^{-1} \left\{\sum_{j=1}^{2}\begin{bmatrix} \cos^2\phi_j & -\sin\phi_j\cos\phi_j \\ -\sin\phi_j\cos\phi_j & \sin^2\phi_j \end{bmatrix}\cdot\begin{bmatrix} x_j \\ y_j \end{bmatrix}\right\} \quad (10)$$

In order to form the EEP for each interception point, the major a_{12} axes and the minor b_{12} axes have to be calculated as:

$$a_{12}^2 = \frac{1}{\sum_{j=1}^{2}\left(1-\cos 2\left(\beta_{12}-\phi_j\right)\right)\cos 2\sigma_j}\sum_{j=1}^{2}\left\{\begin{bmatrix} x_j-x_{T12} \\ y_j-y_{T12} \end{bmatrix}^T \begin{bmatrix} 1+\cos 2\phi_j\cos 2\sigma_j & -\sin 2\phi_j\cos 2\sigma_j \\ -\sin 2\phi_j\cos 2\sigma_j & 1-\cos 2\phi_j\cos 2\sigma_j \end{bmatrix}\cdot\begin{bmatrix} x_j-x_{T12} \\ y_j-y_{T12} \end{bmatrix}\right\} \quad (11)$$

and

$$b_{12}^2 = \frac{1}{\sum_{j=1}^{2}\left(1+\cos 2\left(\beta_{12}-\phi_j\right)\right)\cos 2\sigma_j}\sum_{j=1}^{2}\left\{\begin{bmatrix} x_j-x_{T12} \\ y_j-y_{T12} \end{bmatrix}^T \begin{bmatrix} 1+\cos 2\phi_j\cos 2\sigma_j & -\sin 2\phi_j\cos 2\sigma_j \\ -\sin 2\phi_j\cos 2\sigma_j & 1-\cos 2\phi_j\cos 2\sigma_j \end{bmatrix}\cdot\begin{bmatrix} x_j-x_{T12} \\ y_j-y_{T12} \end{bmatrix}\right\} \quad (12)$$

where $\beta_{12} = \left(1/\sigma_1^2+1/\sigma_2^2\right)^{-1}\cdot\left(\phi_1/\sigma_1^2+\phi_2/\sigma_2^2\right)$ represent the angle between the major axes and the x-axis. For each pairs of bearing lines, the interception point and the EEP by (10), (11) and (12) should be calculated.

After the determination of all $S(S\text{-}1)/2$ interception points, it is possible to fuse all interception points and EEPs in order to estimate the emitter position. The method for fusing multiple interception points with the corresponding EEPs is the same as the method for combining the two-dimensional emitter location ellipses using the equation of an ellipse. Method for combining the two-dimensional emitter location ellipses has been presented in the next section.

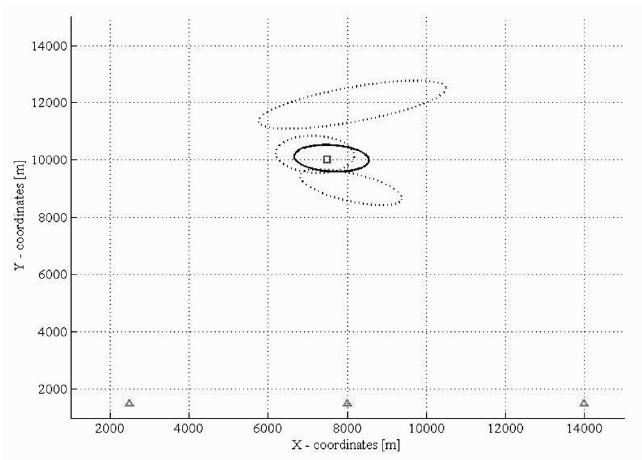


Figure 3. Determination of the emitter position by the fusion of multiple bearing lines method

Fig.3 shows the determination of the emitter position by the fusion of multiple bearing lines method, for the same scenario as in the case of the DPD method. Three ellipses (dashed lines) are estimated for each pair of bearing lines and the ellipse (solid line) represents the EEP obtained through the fusion of multiple EEPs.

C) Mean-squared distance algorithm

The mean-squared distance algorithm is based on minimizing the square of the miss distance of the determined emitter position from the measured bearing lines of position [3]. The sum of the squares of the total miss distance can be expressed as:

$$D = \sum_{s=1}^{S} d_s^2 = \sum_{s=1}^{S}\left(a_s x_T\right)^2 + \sum_{s=1}^{S} 2a_s b_s x_T y_T - \sum_{s=1}^{S} 2a_s c_s x_T + \sum_{s=1}^{S}\left(b_s y_T\right)^2 - \sum_{s=1}^{S} 2b_s c_s y_T + \sum_{s=1}^{S} c_s^2 \quad (13)$$

where a_s=sinφ_s, b_s=-cosφ_s, c_s=$x_s$cosφ_s- $y_s$sinφ_s.

Using statistical estimation arguments, based on the linear system theory, the miss distance in a matrix form is expressed as [7]:

$$\mathbf{D} = \mathbf{HP} - \mathbf{C} \tag{14}$$

In this expression $\mathbf{C} = \begin{bmatrix} c_1 & c_2 & \cdots & c_S \end{bmatrix}^T$, $\mathbf{P} = \begin{bmatrix} x_T & y_T \end{bmatrix}^T$, $\mathbf{D} = \begin{bmatrix} d_1 & d_2 & \cdots & d_S \end{bmatrix}^T$ and $\mathbf{H} = \begin{bmatrix} a_1 & a_2 & \cdots & a_S \\ b_1 & b_2 & \cdots & b_S \end{bmatrix}^T$.

The least-squared error estimator for the emitter location vector **P** is given by [8]:

$$\hat{\mathbf{P}} = \left[\mathbf{H}^T \mathbf{R}^{-1} \mathbf{H}\right]^{-1} \mathbf{H}^T \mathbf{R}^{-1} \mathbf{C} \tag{15}$$

where $(\cdot)^{-1}$ denotes inverse, and $(\cdot)^T$ denotes transpose matrix operations. **R** is a weighting matrix that is selected to optimize calculation. The variance of this estimator is given by [8]:

$$\mathbf{Q} = \left[\mathbf{H}^T \mathbf{R}^{-1} \mathbf{H}\right]^{-1} = \begin{bmatrix} \sigma_x^2 & \rho\sigma_x\sigma_y \\ \rho\sigma_x\sigma_y & \sigma_y^2 \end{bmatrix} \tag{16}$$

D) Simulation results

In order to compare these three methods for the determination of the emitter position to the CRLB, the following three scenarios have been simulated. The comparison of the proposed methods to the CRLB is conducted using the Monte Carlo simulation and averaged over 1000 iterations.

In the first simulation, the AOI is defined as a 125×125 point grid with a sampling resolution of 200 meters (25km×25km). Three DF sensors are arranged inside the AOI at positions (2.5km, 1.5km), (8km, 11.5km) and (14km, 1.5km), respectively. All estimated AOAs are represented by the von Miss PDF with standard deviation σ=3°. It is assumed that there are 49 emitters positioned inside the AOI. For each of 49 emitters, its position and EEP is estimated. For each emitter, the CRLB is visualized as an EEP giving information about both the size and the direction of the error at selected emitter positions (solid line in Figures 4 and 5).

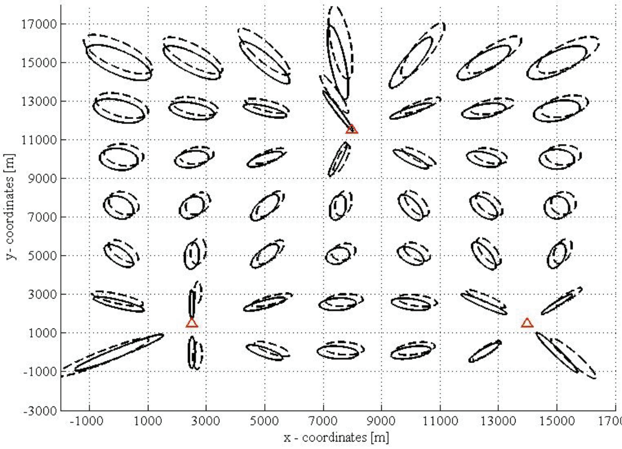


Figure 4. Ellipse Error Probable denoting 50% containment regions: Cramer-Rao EEP (solid line), DPD EEP (dashed line), position of DF sensor (red triangle mark)

The estimated EEPs of the DPD method and the fusion of multiple bearing lines method are shown with dashed lines in Figures 4 and 5. Based on the results shown in Fig.4 it can be concluded that the estimated EEPs obtained by the DPD methods have almost identical size and direction as the CRLB EEP. However, there is some bias between the positions of DPD's EEP and CRLB's EEP. This bias is caused by an error in determining the emitter position. This bias in not so expressed when the fusion of multiple bearing lines method is used. However, the EEPs estimated by the fusion of multiple bearing lines method are of a bigger size near the DF sensor than those estimated by the DPD method.

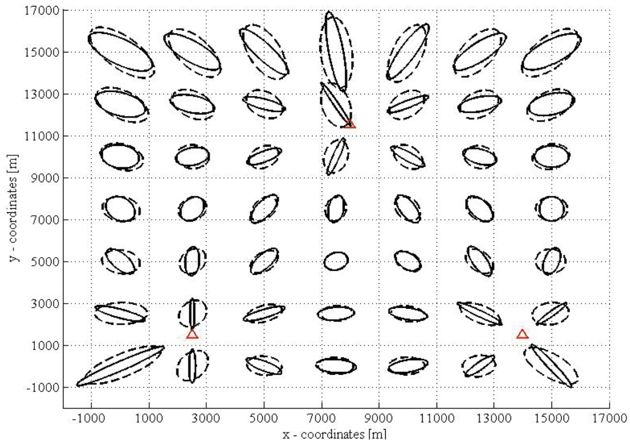


Figure 5. Ellipse Error Probable denoting 50% containment regions: Cramer-Rao EEP (solid line), EEP for fusion of multiple bearing lines method (dashed line), position of DF sensor (red triangle mark)

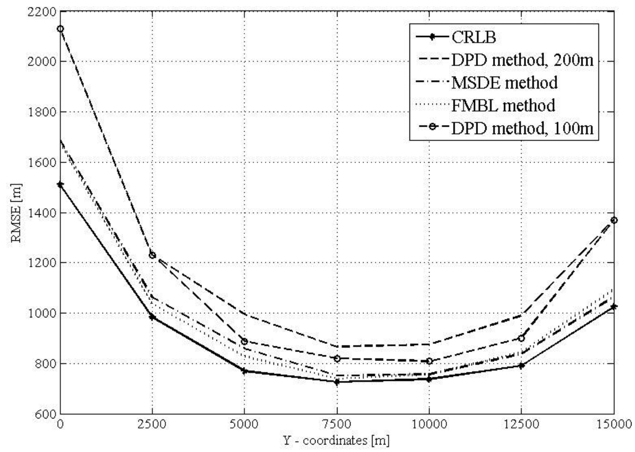


Figure 6. RMSE determination of the emitter position for the emitter positioned at different Y coordinates and a fixed X coordinate of 7.5km

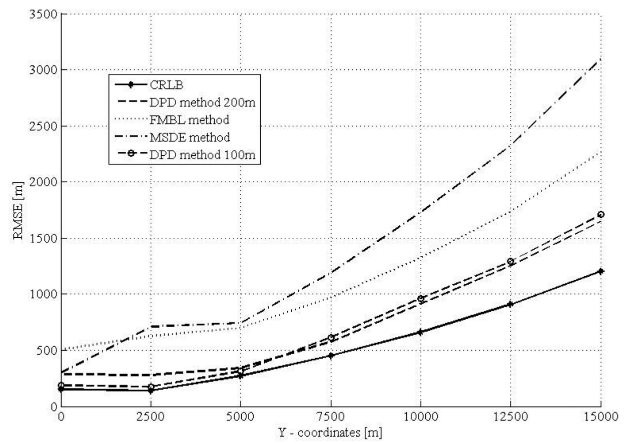


Figure 7. RMSE determination of the emitter position for the emitter positioned at different *X* coordinates and a fixed *Y* coordinate of 1.5km

In the second simulation, we assume that three DFs are positioned at the same X-coordinate of 7.5km and Y-coordinate (2.5km), (8km) and (14km), respectively. The size of the AOI and the emitter position are the same as in the first scenario. All estimated AOAs are represented by the Gaussian distribution with σ_1=3°, σ_2=6° and σ_3=5° for

DFs, respectively. Fig.6 shows the Root Square Mean Error (RMSE) of the determination of the emitter position for the emitters placed at selected coordinates. For the DPD method, there are two estimations of the RMSE location for different sample resolutions - 100m and 200m. Based on the results presented in Fig.6, it can be concluded that the mean-squared distance (MSDE) method and the fusing of multiple bearing line (FMBL) method have the same RMSE location.

In the third simulation, we assume that five DF are positioned at the same *Y*-coordinate of 1.5km and *X*-coordinates are 2.5km, 6km, 10.5km, 14km and 17km, respectively. The sizes of the AOI and the emitter position are the same as in the first scenario. All estimated AOAs are represented by the Gaussian distribution with σ=3° and there is an AOA bias error of 10° at the second DF. Based on the results given in Fig.7, it can be concluded that the DPD method is more resilient to the bias error than the other two methods.

Fusion of multiple emitter location

Multisensor data fusion has become important in order to integrate the individual sensor data into a common operational picture of the battlefield. However, there is still a possibility to improve the quality of the individual sensor data. In this paper, we are interested in improving the data obtained using the ES sensor, especially in improving the emitter position determination. The network composed of these sensors is used to form the COB based on interception and location of radio emitters in the AOI. Modern ES sensors are configured as fast wideband scanning interception systems (wideband direction finders). These systems provide a high probability of detection of all types of emissions with simultaneous estimation of AOA for each detected emission in every scan. However, the obtained data from the wideband direction finder have to be processed in order to provide data that can be integrated with other intelligence data into a common operational picture of the battlefield.

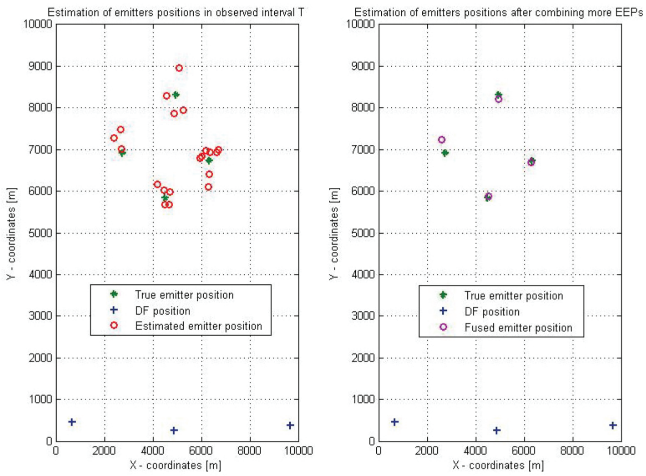
Data from the wideband direction finder are usually inputs in the module for signal pre-classification. The main goals of the pre-classification module are the classification of types of transmission (fixed frequency, frequency hopping, burst), the estimation of duration of emissions, the averaging of AOA and the determination of the quality of measurement. The signal pre-classification could be performed at all ES sensor. After pre-classification, the next step is to separate and group different emissions to emitters, and to form radio-networks from the emitters. This process is complicated for several reasons: the emissions are sporadic, consisting of short bursts of intercepted emissions with log quiescent intervals. In addition, emitters can be used in different radio-networks from the same location. Separating and grouping different emissions into emitters and radio-networks have been performed in the module for forming the COB.

During the COB forming process, more emissions can be associated to each detected emitter. The number of associated emissions to the emitter depends on the emitter activity in the observed time interval. Each emission at the observed time interval can be defined by the state vector composed of four elements $\{\mathbf{p}_i, \mathbf{e}_i, \boldsymbol{\tau}_i, \boldsymbol{\alpha}_i\}$ where the vector $\mathbf{p}_i$ is the estimated emitter positions for the i-*th* emission, $\mathbf{e}_i$ is the associated uncertainties of the estimated position EEP for the i-*th* emission, $\boldsymbol{\tau}_i$ is the set of timestamps for the *i-th* emission and $\boldsymbol{\alpha}_i$ is the determined type of the transmission.

Fig.8 shows a situation when there are four emitters that belong to a radio-network at the AOI (10km × 10km) and there are three ES sensors. It is assumed that in the selected time interval *T* (observation interval) there are 20 emissions that belong to these four emitters. Based on the estimated AOAs of these 20 emissions in COB it is possible to determine 20 emitter positions and their associated EEPs (Fig.8a).

The algorithms for calculating emitter positions presented in the previous section determine the position of an emitter and the corresponding EEP within the emitter lies with specified probability. These EEPs provide a possibility to combine (fuse) more EEPs that belong to the same emitter in order to improve the accuracy of the estimation of emitter positions. This fusing of EEP is usually performed in the COB module.

Fig.8b shows the estimation of emitter positions after fusing emitter positions and associated EEPs that belong to the same emitter.



a) b)

Figure 8. Estimation of emitter positions in the observed time interval *T*; a) estimated emitter position for each detected emission; b) estimated emitter positions after combining EEPs assiciated to each emission

Work [7] presents a method for combining the two-dimensional emitter location ellipses using the equation of an ellipse. The equation of the ellipsoid can be expressed in a matrix form as:

$$\left(X - \hat{X}\right)^{\mathbf{T}} \cdot \mathbf{Q}^{-1} \cdot \left(X - \hat{X}\right) = C \tag{17}$$

where $\hat{X}$ is the true value of X and $\mathbf{Q}$ is a covariance matrix of X and C is a constant corresponding to the ellipse that encloses the observation with the probability P_e. If the ellipse encloses a region that includes a Gaussian random vector with probability P_e, then C=-2ln(1-P_e).

Using the assumption that the observations are statistically independent, it is shown in [9] that the probability density function of the emitter position conditioned on the set of observation is given by:

$$p\left(X|O_1,\ldots,O_I\right) = K\prod_{i=1}^{I} p\left(X|O_i\right) \tag{18}$$

where K is the scaling factor, and I is the number of independent measurements.

Since $p\left(X|O_i\right)$ is Gaussian, the conditioned probability density function of the emitter position for an obtained set of observation can be expressed as:

$$p(X|O_1,\ldots,O_I)=K_1\prod_{i=1}^{I}\exp\left\{-\frac{1}{2}(X-O_i)^T\mathbf{Q}_i^{-1}(X-O_i)\right\} \quad (19)$$

and

$$p(X|O_1,\ldots,O_I)=K_1\exp\left\{-\frac{1}{2}\sum_{i=1}^{I}(X-O_i)^T\mathbf{Q}_i^{-1}(X-O_i)\right\} \quad (20)$$

The optimal estimate for any symmetric cost function is the same for Gaussian distributions and results in the minimum of the argument of the exponential in (20). That minimum can be expressed as:

$$\hat{X}=\left(\sum_{i=1}^{I}\mathbf{Q}_i^{-1}\right)^{-1}\sum_{i=1}^{I}\mathbf{Q}_i^{-1}O_i \quad (21)$$

and its covariance matrix is

$$\mathbf{Q}=\left(\sum_{i=1}^{I}\mathbf{Q}_i^{-1}\right)^{-1} \quad (22)$$

Equation (21) is used to calculate a new emitter location, and (22) to calculate a new EEP. The major and minor axes have the lengths $2\sqrt{C\lambda_1}$ and $2\sqrt{C\lambda_2}$, respectively, where λ_1 and λ_2 are eigenvalues of the matrix $\mathbf{Q}$.

In the following simulations, we compare the obtained results of fusing multiple emitter positions for three methods for the determination of emitter positions. In the simulated scenario, it is assumed that five DF are positioned at the same *Y*-coordinate at 1.5km and the *X*-coordinates are 2.5km, 6km, 10.5km, 14km and 17km, respectively. The emitter positions are (8950m, 10000m) in the first scenario and (8950m, 17500m) in the second scenario. All estimated AOAs are represented by the Gaussian distribution with σ=3°. For each emitter there are ten estimations of emitter positions for fusing multiple EEPs. The RMSE of the emitter position is calculated after combining EEPs and the estimation of a new emitter position. The obtained results are averaged over 100 iterations using the Monte Carlo simulation.

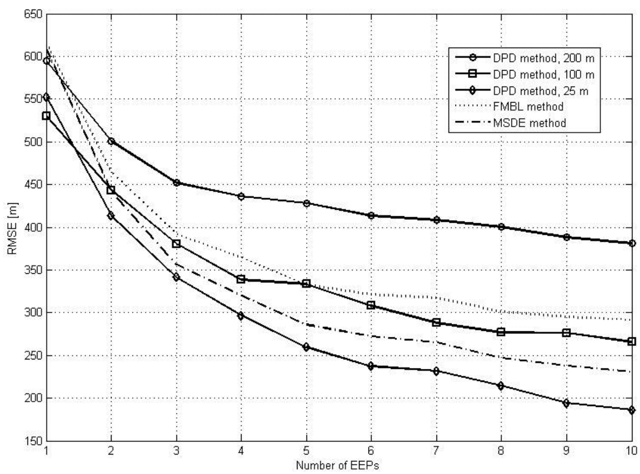


Figure 9. RMSE determination of the emitter position after fusing different number of EEPs for the emitter positioned at 8950m, 10000m

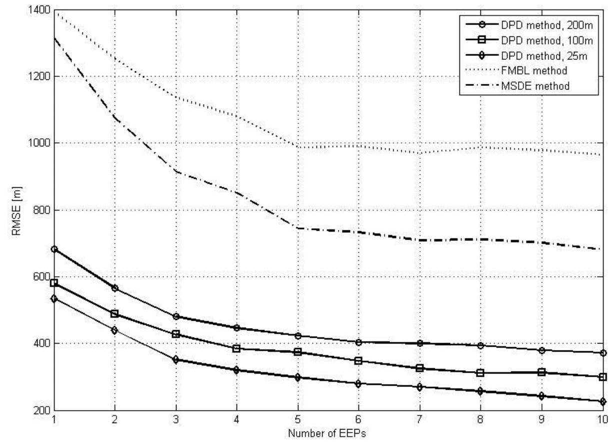


Figure 10. RMSE determination of the emitter position after fusing different number of EEPs for the emitter positioned at 8950m, 17500m

Figures 9 and 10 show the RMSE estimation of the emitter position after combining the emitter positions based on equation (19) for the DPD method, the FMB method and the MSDE method for the first and the second scenario, respectively. In the first scenario, when the emitter position is closer to the sensors, the DPD method with a sampled interval of 25 m is better than the FMB method and the MSDE method (Fig.9).

In the second scenario, the emitter position is farther from the sensors. In this case, the DPD method with a sampled interval of 25 m outperforms the FMB method and the MSDE method (Fig.10).

Based on these results, it can be concluded that the DPD method shows a better performance than the other methods.

Conclusion

Determination of an emitter position is very important in ES systems. There are usually more estimated emitter positions that belong to the same emitter in the observed time interval. This fact should be used during the process of forming the COB. There is a possibility that fusing more estimated emitter positions significantly improves the accuracy of the determination of the emitter position.

In this paper, three methods for the determination of the emitter position have been compared in order to improve the estimation of emitter positions in the ES sensor before and after forming the COB, i.e. before and after the fusing of multiple emitter positions. On the basis of the obtained results, it can be concluded that the DPD method with appropriate sampling intervals has a better performance than the fusion of multiple bearing lines method and the mean-square distance algorithm in terms of location accuracy. This is achieved at the cost of computational complexity that depends on a sampling interval.

Future research will consider the problem of separating and grouping emissions to different emitters in the case of spatially close emitters in the AOI.

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Fuzija procenjenih pozicija radio-predajnika

Fuzija podataka u višesenzorskim sistemima je veoma važna u odbrambenim sistemima. Fuzija podataka se koristi za objedinjavanje podataka dobijenih od pojedinačnih senzora u združenu operativnu sliku bojišta. Međutim, još postoji mogućnost poboljšanja kvaliteta pojedinačnih senzora. U ovom radu, ispitivana je mogućnost poboljšanja kvaliteta podataka od pojedinačnih senzora, odnosno senzorskih mreža koje se koriste u sistemima za elektronsko ratovanje (ER). Nove metode i tehnike za procenu pozicije radio-predajnika su upoređene u ovom radu, kao što su metoda diskretne gustine verovatnoće (Discrete Probability Density - DPD), objedinjavanje više procenjenih azimuta i algoritam baziran na metodi najmanjih kvadrata. Ove metode su ispitivane da bi se ustanovila njihova primenjivost u procesu formiranja elektronske slike bojišta. Predložena je procedura za formiranje elektronske slike bojišta zasnovana na fuziji procenjenih pozicija radio-predajnika.

Ključne reči: **fuzija podataka, elektronski rat, elipsa poverenja, radio-lokacija, radio-predajnik.**

Слияние оценочных позиций радиопередатчика

Слияния данных в мультисенсорных системах являются очень важными в оборонительных системах. Слияния данных используются для интеграции данных, полученных от отдельных датчиков, в совместную оперативную картину поля сражения. Тем не менее, есть ещё возможность улучшения качества отдельных датчиков. В данной работе мы изучили возможность повышения качества данных от отдельных датчиков и сенсорных сетей, которые используются в системах радиоэлектронной борьбы (ЭБ). Новые методы и методики для оценки положения радиопередатчиков сравниваются в этом исследовании, такие как метод дискретной плотности вероятности (Discrete Probability Density - DPD), объединение нескольких расчётных азимутов и алгоритм, основанный на методе наименьших квадратов. Эти методы рассмотрены с целью определить их применимость в процессе формирования электронной картины поля сражения. Процедура формирования электронной картины поля сражения, изображена на основе слияния оценочных положений радиопередатчика, предлагается в этой статье.

Ключевые слова: **слияние данных, радиоэлектронная борьба, уверенность эллипсы, радиолокация, радиопередатчик.**

Fusion des positions estimées des émetteurs radio

La fusion des données dans les systèmes multi sensoriels est très importante pour les systèmes de défense. Cette fusion est utilisée pour intégrer les données obtenues par des capteurs particuliers dans la commune image opérationnelle du champ de bataille. Cependant, la possibilité d'amélioration des capteurs particuliers existe toujours. Dans ce travail on a étudié la possibilité d'améliorer la qualité des données obtenues par les capteurs particuliers c'est-à-dire des réseaux sensoriels utilisés chez les systèmes pour la guerre électronique. Les nouvelles méthodes et les techniques pour l'estimation de la position d'émetteur radio ont été comparées dans le cadre de ce travail, comme la méthode de la discrète densité de probabilité (Discrete Probability Density – DPD) , l'intégration de plusieurs azimuts estimés et l'algorithme basé sur la méthode des carrées les plus petits Ces méthodes ont été étudiées pour établir leur applicabilité dans le processus de la formation de l'image électronique du champ de bataille. La procédure de la formation de l'image électronique du champ de bataille, basée sur la fusion des positions estimées des émetteurs radio, est proposée dans ce travail.

Mots clés: **fusion des données, guerre électronique, ellipse de confiance, radio location, émetteur radio.**