Theoretical and Experimental Investigations of the Multi-Band Radar Complex for Environmental Monitoring

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\textbf{Abstract}—Basic principles of the multi-site environmental monitoring radar complex design are considered. Advantages of proposed scheme in comparison with another architectures are analysed. Experimental and simulation results which confirms an effectiveness of proposed solutions are given.

\textbf{Index Terms}—Multi-Band Radar Complex, Data Fusion, Target Tracking.

I. INTRODUCTION

Nowadays radars are common used as a tool for the environmental researching (e.g. as the ecological remote sensing tool [1]). However one radar is often cannot provide all parameters which are necessary for monitoring. E.g. it's quite difficult to provide with one radar wide coverage area and the high accuracy at the same time. And it's impossible with one radar making measurements in different frequency ranges. An idea appears to combine information from a few radars so that the data fusion would provide the required amount and quality of information about monitoring targets.

II. DESIGN PRINCIPLES FOR THE MULTI-BAND RADAR COMPLEX

Proposed idea is based on the fusion and joint utilization of the information from the distributed radars of different wave-bands for the purposes of common information field creation and performance improvement for the fundamental tasks (target detection, coordinates evaluation, tracking, classification) [2]. Already deployed radars of different affiliation (air traffic control radars, weather radars, ecological monitoring radars and so on) with overlapping coverage areas are selected to be combined.

Maximum using of available radars and a minimum of modernization reduce the cost of the radar complex in comparison with the creation and deployment of a new network of the ground radars [3]. The problems in this case are: selection of the required radars, optimization of their operating modes and the performance characteristics for integration into the local network, and development and implementation of algorithms for the radar data fusion.

Improving the radar performance in the Multi-Band Radar Complex (MBRC) in comparison with the single radar is achieved by the following factors: 1) the distribution of radars in the region which provide the observation from different foreshortenings, 2) the presence of several radar frequency bands with quite different conditions of propagation and reflection properties of radar signals, 3) increasing the amount of information about the targets due to data presented from several radars.

The results are an increasing of the coverage area, accuracy of coordinates evaluation and target tracking, noise-immunity, and extension of the vector of the measured parameters, and improving the average track duration, the track initiation time and the track initiation probability.

The radars cooperation is carried out as follows. Each radar detects targets and measures their coordinates independently. One radar measurement includes set of the radar target parameters obtained during preprocessing. In general case radar measurement includes the target parameter vector (range, azimuth, elevation, radial velocity), the measurement errors of the vector components, the
radar number, and the time of detection. All the data are sent over communication lines to the fusion center.

III. DATA FUSION IN THE MULTI-BAND RADAR COMPLEX

In data fusion methods for the complex with independently working radars of different wave-bands there is a choice between the measurement fusion and track fusion [3]. In first case information about all of detected targets transmits to the fusion center, in the second – information only about tracked targets, i.e. targets tracked by the radar. Track fusion reduces the carrying capacity requirements of communication lines between radar and fusion center due to false measurements filtering; reduces computational power requirements of the fusion center because a part of processing is carried out by the radar. Also there is possibility of adaptation of track processing algorithms to the real time situation on the each radar.

With measurement fusion greater information is arrived to the fusion center, and it begins to come here earlier – before radar will initiate track for this target. It provides faster the new track initiation because latter is carried out based of information not from single radar, but from a few radars. Greater information increases track duration and tracking accuracy, decreases probability of track deletion. Other advantages of measurement fusion are faster a maneuver detection and necessity of creation only one tracking system, that simplifies its adjusting and exploitation and allows to make operative alterations, for example under necessity of tracking targets on the new types. Paying for these advantages is increased probability of false track initiation. Due to the more advantages measurement fusion in MBRC is chosen.

As far as their forming in radar measurements are sent out over communication lines to the fusion center. The measurement buffer is used to remove different and random time delays in communication lines and for measurement sorting accordingly their times of creation.

Information fusion is carried out during joint tracking (Fig. 1).

![Diagram](image)

**Fig. 1.** Information fusion during joint tracking.

At the target tracking system design first of all it is necessary to define the types of targets which complex must to detect and track; and to select the basic features of their moving. Based on this assumptions the target motion model is developed for utilization by the tracking algorithms.

During joint radar information processing measurement from different radars are have to be brought to the common point of space. It is carried out by the transformation of the vectors of measured target parameters and their correlation matrices from the polar coordinate system (CS), related to single radars, to the so called basic coordinate system, related to the fusion center. It is preferable to use the rectangular coordinate system as basic CS.

Target tracking is carried out in presence of false measurements and nearby targets, so algorithm for the association of new measurements with tracks is needed.
On the first stage of association – gating – measurements are compared with all predicted tracks. If after gating some measurement associated with single track, it goes to this track and association is finished.

In case of a several marks falls into the single gate or one mark falls into the several gates, second stage of exact association is needed. Most widespread techniques of exact association are probabilistic (PDA, Probabilistic Data Association, for single target tracking and JPDA, Joint PDA, for multi-target tracking) and Multi Hypothesis Tracking (MHT).

The filtering algorithm must provide tracking of the target moved according to the accepted model. The type of filter used is determined by the object motion model and type of probability density of the radar measuring process: for a linear model and Gaussian distribution Kalman filter is used, for nonlinear model and Gaussian distribution - Extended Kalman filter (EKF) or Unscented Kalman Filter (UKF), at for nonlinear model and non-Gaussian distribution - Particle Filter. If target is able to execute a maneuver, filter with maneuver detector or multimodal filter is used (for example, Interactive Multi Model filter, IMM).

New track initiation is started after finding a measurement, not associated with one of the existing tracks. Usually track initiation consists of two stages: tentative track formation and track confirmation. In multiposition complexes tentative track formation time \( T_{\text{conf}} \) and track confirmation time \( T_{\text{conf}} \) during which the set of specified numbers of measurements expects from this target at appropriate stage, is assigned. Multi-position track initiation algorithm based on the statistical sequential analysis is more preferable. It provides minimum analysis time among all algorithms with the identical errors of the first and second kinds; also it is convenient for realization in a multi-position complex. A basic criterion for track deletion is "no measurements during time \( T_{\text{del}} \)".

Simultaneous estimation of motion parameters (centroid) and form parameters (diameter for example) during tracking of extended target (i.e. targets occupied several resolution cells) is produced. For kinematics targets moved under influence of some deterministic (not random) factors, input level \( u \), taken into account in the state equation, will have two components – deterministic and probabilistic.

IV. SIMULATION AND FULL-SCALE EXPERIMENT RESULTS

The quantitative analysis of joint processing was realized with computer simulation and full-scale experiment. Simulated complex was consist of four X-band radars (range mean-square error (MSE) 250 m, azimuth MSE 0.5°, detection probability of target with radar cross-section about 10m² on height of a 10 km and distance 250 km – 0.5) located on the cornes of square with a side a 50 km, and one VHF radar (with above parameters of 600 m, 1°, 0.8) located at the square center. Simulated target was a small airplane (point target). Proposed fusion method was compared with track fusion. The most substantial improvement was fixed for the parameters of true target track initiation: mean time of track initiation decreased in 3.7 times, true target track initiation probability increased at 35%. Tracking accuracy improvement for straightforward motion arrived at 30% (in the stationary filter mode – 15%). Average track duration increased at 10%, and it was more substantial that it took values near to unit.

In a full-scale experiment three radars took parts: radar "Alpha" (frequency 9430 MHz, type of signal – PSK on the code of Barker, 13 characters long, quantum duration 1 µs, repetition period 400 µs, velocity resolution 0.15 m/s, azimuth and elevation beam width 1.09° and 1.06°); MRL-5 (frequency 2950 MHz, pulse width 2 µs, repetition frequency 500 Hz, coherent integration time 42 ms, azimuth and elevation beam width both 1.5°); P-18 (frequency 150-170 MHz, pulse width 5 µs, repetition period 365 Hz, azimuth and elevation beam width 6° and 27°, coherent integration time 0.166 s) [4].

Tracking accuracy for the small airplane in the complex with the measurement fusion and in single radars was examined. Track built by onboard GPS receiver was used as a reference. On fig. 2 examples of the positioning errors measured during one of tests for all radars and complex are presented. For radar "Alpha" an average error was 70-150 m, for MRL-5 – 140-210 m, for P-18 – 145-220 m, for MBRC – 70-150 m (like in "Alpha", but these values in MBRC corresponds to the greater track duration). This chart also illustrates increasing of the mean track duration. The average (over the all tests) tracking accuracy in complex was higher in 1.25-1.4 time, increasing of mean track duration for different experiments was 5-25%.
V. CONCLUSION

In this paper the concept of constructing multi-band radar complex is shown. The concept allows to: combine radars with different the frequency bands; combine fixed and mobile radars (if radar is mobile than the radar measurement includes the radar coordinates at the measurement time); increase the radar amount without making any major changes in the data fusion algorithms; add on other (not radar) remote sensors such as infrared sensors, sonar, optical sensors etc. The results obtained during simulation and the full-scale experiment confirm the efficiency of the proposed concept and its advantage in comparison with a single radar from point of the coordinate evaluation accuracy and the tracking reliability.

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