Analysis of Chosen Results Based on Trials with Distributed and Collocated Passive-Active Radars

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Abstract—In the course of NATO SET-195 RTG work, a field trial with active and passive PCL sensors was conducted. The aim of the trial was to compare experimental results with DMPAR (Deployable Multiband Passive-Active Radar) simulations. Although DMPAR has been devised as collocated receiver system, trials were planned with collocated as well as distributed receiver configurations. Received data has shown that distributed configuration can and will fill in the gaps in the radar coverage created by terrain shadowing or multipath propagation. Also, the overall score in terms of Track Visibility (TV) and Probability of detection (Pd) have been improved in the collocated configuration. Results of the trials have confirmed operational properties of passive-active sensor proposed by SET-195. In this paper a short introduction summing up SET-152 and SET-195 will be presented. Next, received results of collocated and distributed DMPAR will be shown, analyzed, compared and commented. Now, using those results one can analyze and project on operational characteristics of a distributed DMPAR.

Index Terms—passive PCL sensors, active radar, multistatic configuration, collocated receiver configuration, distributed receiver configuration, Deployable Multiband Passive Active Radar (DMPAR)

I. INTRODUCTION

The Deployable Multiband Passive Active Radar (DMPAR) concept has been originally proposed by [1], [2] and the SET-152 RTG in the Final Report of the group [3]. In [3] approach, a collocated system consisting in 4 passive and active components has been connected through the algorithms of centralized and decentralized fusion of signals or plots, respectively. Performed simulations gave promising results and through the course of work of SET-195 [1] these were confirmed by experimental data. The scenarios from trials on which we registered signals and data are described in [1], [4]. The algorithms of signals and data fusion were developed on basis of [2], [5] and described in [6]–[9].

Most notable advantages of the DMPAR approach over typical approach using monostatic active radars and passive PCL systems without data fusion are:

- enhanced detection probability;
- greater localization accuracy and stability of tracking;
- resistance to noise and directed jamming.

These traits of the system are of great importance as on the modern warfare radars often have to deal with the problem of detection of objects with very small RCS.

In the [6]–[9] papers we showed centralized (fusion of signal statistics) and decentralized (fusion of detections) fusion strategy, analysis of system probability of false alarm, threshold management for centralized and decentralized processing and show chosen representatives of registered results that prove mainly simulation results with collocated scenario. In this paper based on results of registered signals and data described in [1] we will show comparable results of detection for collocated and distributed passive-active system scenario and discuss it.

II. SYSTEM PROCESSING SCHEME CONCEPT

In this paper we analyze a system which is described in [7], [9], that consists of high power, low frequency, long range radar (denoted as Early Warning Radar – EWR) and a set of collocated (or distributed) active and passive components - DMPAR (see fig. 1).

The scheme of data processing in the system has been presented on fig. 2. The first element is the EWR unit which continuously scans the area for targets. It works independently with its own processing, detection and tracking algorithms. It is not perceived by the target as a threat, because its performance is low and does not satisfy requirements to engage the target successfully.

Figure 1. Schematic description of analyzed system.
Our aim is to show performance of the passive components that are cued by EWR and relate it to performance of the active component working independently or in cooperation with passive elements. Although passive and active components are collocated, we assume that they are not necessarily mounted on one platform as was the case in [2], [3], but they share the common surveillance area. We also assumed that active and passive components can be distributed [1], [4]. What is more, we assume that we use our active component at a last resort or in the last moment of target engagement.

The EWR outputs its data in a form of tracks and sends them to the collocated DMPAR system (by means of Command and Control system).

Our described system may work in 3 modes of operation, specifically:

- in mode A, only the passive radars are operational and are being cued by the EWR. The active component is activated during the last second before the engagement.
- in mode B, only active radar is operational and cued by the EWR.
- in mode C both active and passive components are operational.

Due to the operational requirements, modes B and C may not be used at all, as they can warn the target of the presence of high-fidelity active component (i.e. a Fire Control Radar) and it may break its planned course of action and steer out of the engagement zone.

As cueing information is fed into each channel of the passive component (each transmitter-receiver pair) and active Fire Control component the data from cued regions is provided on a per-target basis to centralized detection module (fig. 3). In the same time each sensor continues its operation and all sensor detections are sent to the decentralized detection module. This way of operation allows for simultaneous operation of data and signal fusion on separable areas of detection grid.

Thanks to the feeding the passive and active FC radars by the exogenous radar tracks (cueing by EWR), covert tracking of aerial targets can be continued by the centralized and decentralized fusion. The added value of such approach is the extended range of passive and active radar (DMPAR), that is not limited to one of its working channels. If the target is located within the operational range of the passive and active radars and has not been detected by the EWR, the decentralized fusion is performed as well and may still provide detection and tracking of the target.

### III. CENTRALIZED AND DECENTRALIZED FUSION STRATEGY

Following the work presented in [2], [3], [5], [6] we can divide our approaches to data fusion into two algorithms:

- decentralized fusion on the level of plots (detections);
- centralized fusion on the level of signals (signal statistics).

In case of the decentralized fusion each of the sensors in the sensor network operates autonomously. The detection process is performed on the sensor, utilizing any given algorithm that leads to a binary decision $D_d \in \{0, 1\}$ where $0$ indicates no detection of target and $1$ indicates a positive detection. Probability of false alarm $P_{fa}$ is the only constraint imposed by the sensor network. At the central decision node, detections from each sensor are collected and central decision is made following the rule $k$ out of $m$, where $m$ is the total number of participating sensors and $k$ is minimum number to indicate a positive detection.

In the centralized fusion scheme, at the central decision node a combined statistic of signal in each channel is calculated as:

$$D = \sum_{i=1}^{m} w_i d_i^2,$$  \hspace{1cm} (1)

where weighting factor is $w_i = \frac{\text{SNR}_i}{\text{SNR}_i + \text{N}}$, $\text{SNR}_i$ is the SNR at the tested position, $N$ is the overall mean noise floor level in the vicinity of the tested position, and $d_i$ is the amplitude of the signal at the cell under test. This statistic is then compared to a predefined threshold, which guarantees certain probability of false alarm.
IV. PROCESSING OF REGISTERED MEASUREMENTS IN DMPAR

A. Introductory assumptions

In off-line processing of registered measurements [6] we assumed that both decentralized and centralized fusion of DMPAR systems consist of \( N \) individual radars (channels). It means that there is a channel for each separate transmitter and/or separate frequency and/or separate band. In [7], [9] we described DMPAR threshold management. Based on this we have set false track initiation probability to \( 10^{-6} \), resulting in a single refresh integral false alarm probability equal to \( 4.6 \times 10^{-3} \). We also assume that there is a common refresh period for all the channels.

V. ANALYSIS OF DATA FROM FIELD TRIALS MADE IN THE CZECH REPUBLIC (DETOUR TRIALS)

In the activities of the NATO task group SET-195 "DMPAR Short Term Solution Verification" on the Czech airport near Hradec Kralove field trials were conducted in order to collect data for further analysis on the main group purpose. In the 4-days of research made in the first days of September 2014 five institutions took part, both domestic and foreign. The sensors used in measurements are listed in the table I.

<table>
<thead>
<tr>
<th>No</th>
<th>Institution</th>
<th>Codename</th>
<th>Type of sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PIT-RADWAR</td>
<td>S band</td>
<td>Active</td>
</tr>
<tr>
<td>2</td>
<td>PIT-RADWAR</td>
<td>C band</td>
<td>Active</td>
</tr>
<tr>
<td>3</td>
<td>Warsaw University of Technology</td>
<td>WUT-FM</td>
<td>Passive-FM</td>
</tr>
<tr>
<td>4</td>
<td>Warsaw University of Technology</td>
<td>WUT-DVB-T</td>
<td>Passive-DVB-T</td>
</tr>
<tr>
<td>5</td>
<td>Fraunhofer FHR</td>
<td>FHR</td>
<td>Passive-DVB-T</td>
</tr>
<tr>
<td>6</td>
<td>Norwegian FFI</td>
<td>FFI</td>
<td>Passive-DVB-T</td>
</tr>
<tr>
<td>7</td>
<td>Czech ERA</td>
<td>ERA</td>
<td>Passive-FM</td>
</tr>
</tbody>
</table>

In order to process data with multiband fusion algorithms the collected data were subset from the whole raw data registered by each of the sensors. Every institution taking part in the research has agreed to deliver raw data but only locally corresponding to the object of task group research.

Data from two flight trajectories which have been registered by all sensors have been chosen for further analysis. According to the flight plan it was flight 2 (FL2) and flight 11 (FL11). On fig. 4 and fig. 5 maps with flight trajectories and positions of radar sensors are shown.

Radar systems consisting in PITRADWAR’s dual band (S and C band), and passive radars of FFI (DVB-T) and ERA (FM) were placed at the airport of the Hradec Kralove; FHR’s and WUT’s passive radars (DVB-T) were located near Jaromer; and remaining WUT passive radars (FM, DVB-T) were deployed near Chotec. When referring to the configuration as collocated only the measurements from radars (active and passive) from the first location (airport Hradec Kralove) were used; for distributed configuration measurements from all radars (passive and active) from all locations were exploited.

A. Quality measures of DMPAR processing based on registered measurements

The goal of the research of DMPAR idea is to evaluate the quality improvement based on DMPAR signal processing [4], [7]. The off-line processing results were shown in [1]. We propose two measures of quality to evaluate a different processing scheme. Based on these measures we make the comparison between the results of the DMPAR processing and, for example, single sensor processing. Below are these measures of quality:

- \( P_{det} \) – probability of detection as a function of the distance from a specified location;
- TV – track visibility.

The definitions of these measures are described in [1], [6].

B. Comparison of representatives results from SET-195 and SET-152

Comparing figs. 7 and 8 with fig. 6, one can note, that range improvement of collocated DMPAR configuration acquired via simulations for centralized and decentralized fusion, has been confirmed by DETOUR trials registered and processed data.
Please note figs. 7 and 8 lower performance of the decentralized processing, in comparison to both centralized and S-band only processing. This is due to significant number of sensors with low SNR (9 passive channels) shadowing relatively small number of sensors with high SNR (2 active channels). Due to the K out of N rule of decentralized detection, active radar performance is lost in the number of passive channels. With the centralized processing, low-SNR channels are scaled down in the threshold statistic which gives way for the signals from active component with high SNR. In case of far-range detections, most of the channels start to face low SNR levels, and decentralized processing outperforms centralized scheme.

![Graph](image)

Figure 6. Chosen result from the SET-152 report. Shown as a reference for comparison with experimental results.

![Graph](image)

Figure 7. Comparison of detection range in collocated configuration, flight FL2.

C. Comparison of representatives results from DETOUR trials

On the fig. 9 comparison of centralized and decentralized processing in case of distributed antennas (all channels) is presented. In contrary to the collocated case (fig. 7), decentralized processing outperforms centralized in most part of the range. This may be due to the fact, that far-range region for the active, ERA-FM and FFI-DVB-T components is close-range to the sensors in Jaromer or Chotec. Then, at least half of the sensors have reasonable SNR levels, allowing for decentralized scheme to work, whereas SNRs are still low for the centralized scheme to work (far-range and shadowing for active component especially). During flight 11, SNR was higher (due to higher RCS of the target) and trajectory was flown on higher altitude than FL2. This resulted in relatively high SNR in most of the sensors and comparable performance of decentralized and centralized processing in distributed configuration (fig. 9).

Comparing figs. 7 and 8 (collocated configuration) with figs. 9 and 10 (distributed configuration) for all sensors used in these configurations we conclude that in the distributed case, the detection performance is influenced by trajectory, system configuration and constellation, and type of target. The bigger coverage in the far-range in distributed configuration is mostly provided by WUT-FM sensor based in Jaromer.

![Graph](image)

Figure 8. Comparison of detection range in distributed configuration, flight FL11.

Comparing figures figs. 11 to 14 one can note that in distributed scenario, as long as only FM and DVB-T receiver/transmitter pairs are used, ranges for the FM pairs
are greater irrespective of flight trajectory. Centralized and decentralized fusion give comparable results in this scenario. However, for DVB-T the decentralized fusion strategy gives shorter ranges when compared with the centralized fusion strategy.

Looking at results presented in the table II one can conclude that TV is always greater in distributed scenario compared with collocated scenario. The cause of this behaviour lies in the fact, that multistatic configuration gives more opportunities for object observation than monostatic or quasi monostatic configuration. As has been already discussed, in the distributed case, the detection performance is influenced by trajectory, system configuration and constellation and type of target.

**Table II**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Decentralized processing TV</th>
<th>Centralized processing TV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collocated</td>
<td>0.6517</td>
<td>0.7992</td>
</tr>
<tr>
<td>Distributed</td>
<td>0.9733</td>
<td>0.9112</td>
</tr>
</tbody>
</table>

**VI. Summary**

During conducted processing of registered data, around 130 graphs were generated for different cases. These graphs give very detailed info for presented cases. However, in order to compare centralized and decentralized performance in collocated and distributed configuration and also to have clear
results, in this paper we compare only most representative figures and tables concerning statistical results giving us general conclusions about quality processing in DMPAR.

After this comparison we can say that:

1) Range improvement of collocated DMPAR configuration, has been confirmed based on DETOUR trials.

2) In the distributed case (fig. 9) contrary to the collocated case (fig. 7), decentralized processing outperforms centralized in most part of the range. Relatively high SNR in most of the sensors can give comparable performance of decentralized and centralized processing in distributed configuration.

3) Detection performance is influenced by trajectory, system configuration and constellation, and type of target. The bigger coverage in the far-range in distributed configuration is mostly provided by WUT-FM sensor based in Jaromer.

4) Ranges for the FM pairs are greater that for DVB-T irrespective of flight trajectory. For DVB-T decentralized fusion strategy gives shorter ranges comparing to centralized fusion strategy.

5) TV is always greater in distributed scenario than in collocated scenario. The cause of this behaviour lies in the fact, that multistatic configuration gives more opportunities for object observation than monostatic or quasi monostatic configuration.

As a general conclusion, it should be stated that performed field research of described DMPAR parameters ($P_{det}; TV$) was not optimized in terms of sensor deployment for the distributed scenario. This was due to limitation of states available for research. In the real conditions, utilization of a mission planning software seems necessary to obtain optimal parameter values.

REFERENCES


