Fusion of tri-dimensional surveillance radar data

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***Abstract.** The paper deals with the problem of impact point prediction of Ballistic Targets (BT) by processing measurements acquired by two 3D surveillance radars. It is assumed that the radars acquire a limited number of measurements that do not encompass the whole target trajectory; thus the established target track has to be extrapolated ahead in time in order to predict the coordinates of the impact point. The updating and testing of the data extractor (DE) of a notional tri-dimensional surveillance radar system is presented in this paper; the modified hardware and software is capable of acquiring, managing and fusing tracks pertaining to the radar system housing the DE and to other systems connected to the DE itself.*

Keywords: Multi radar tracking, data association, estimation, track fusion.

1. Introduction

One of the most important requirements for the anti-ballistic target (BT) function implemented in tri-dimensional surveillance radars is the prediction of the BT impact point (IP) and launch point (LP). It has been found that a relevant improvement to the IP prediction is obtained via the fusion of data acquired from two or more homogeneous surveillance systems [1].

The updating and testing of the data extractor (DE) of a notional tri-dimensional surveillance radar system is presented in this paper; the modified hardware and software is capable of acquiring, managing and fusing tracks pertaining to the radar system housing the DE and to other systems connected to the DE itself.

The updated DE is fed with BT simulated trajectories and it uses the same hardware and software architecture of the equipment installed on a real system; therefore, combined with a properly designed Multi-Radar Scenario Simulator, it becomes a trustworthy demonstrator for data fusion improvements on IP estimation performances.

It is currently proposed to apply the data fusion to a network of surveillance systems having a reasonable overlap of coverage such that the BT is detected and tracked by all the systems involved in the radar network, as shown in following Figure 1-1.

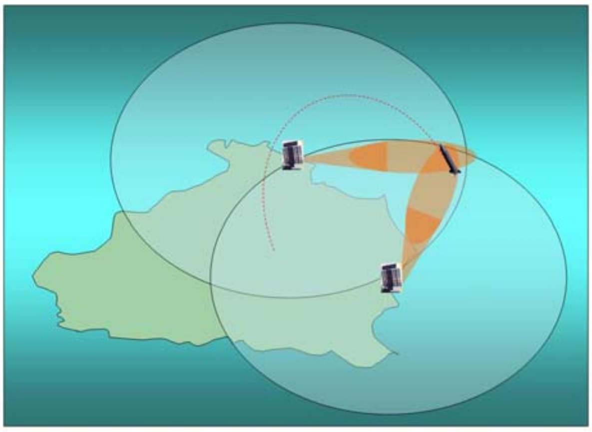


Figure 1-1 Typical surveillance fence

The paper is organized as follows: next section 2 briefly recalls the BT kinematics used for the BT trajectories generation and the Extended Kalman Filter (EKF) designed for BT tracking ; section 3 resumes the data fusion techniques applied for achieving the IP estimation; section 4 is dedicated to the hardware and software demonstrator description; section 5 presents the achieved results; section 6 reports some conclusions and section 7 a list of references.

2. BT kinematics

Three main forces affect the BT motion: thrust, drag and gravity [2-4]. For the sake of this paper, it is assumed that the BT is in the cruise phase during the BT state vector estimation while drag and gravity are acting on the target body during the re-entry phase. The drag acceleration expression is [2-4]

$$\mathbf{a}_{drag}=\begin{bmatrix} a_{dragx} \\ a_{dragy} \\ a_{dragz} \end{bmatrix}=-\frac{1}{2}\frac{\rho(z)\cdot g_0}{\beta}\sqrt{\dot{x}^2+\dot{y}^2+\dot{z}^2}\cdot\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} \qquad (2.1)$$

where β is the ballistic coefficient (N/m^2), $\rho(z)$ is the air density function of the height:

$$\rho(z)=1.21907\cdot e^{-z/9146.64} \qquad (2.2)$$

$\dot{x},\dot{y},\dot{z}$ are the velocity components of the BT along the three axes of a Cartesian reference system. The gravity acceleration is considered constant, g_0=9.8m/s^{2}and directed along the z-axis.

The measurements, collected by the radar for target tracking, are the range r, elevation ε and azimuth ϑ

3. Tracks fusion equations

A number of strategies have been conceived for fusing information (plots and/or tracks) generated by N sensors. In the case of N tracks, they are combined in order to achieve a single multisensor track for each target. This is performed after having associated the corresponding tracks by resorting to a statistical test [5-7]. If the tracks are independents, they are merged into a single equivalent track as follows (see [5, page 17]).

$$\hat{\mathbf{s}} = \hat{\mathbf{P}} \cdot \sum_{i=1}^{N} \left[\hat{\mathbf{P}}_{\mathrm{i}}\right]^{-1} \hat{\mathbf{s}}_{\mathrm{i}} \tag{3.1}$$

$$\hat{\mathbf{P}} = \left\{ \sum_{i=1}^{N} \left[\hat{\mathbf{P}}_{i}\right]^{-1} \right\}^{-1} \tag{3.2}$$

where:

$\hat{\mathbf{s}}$ = state vector of multisensor track,

$\hat{\mathbf{P}}$ = covariance matrix of $\hat{\mathbf{s}}$,

$\hat{\mathbf{s}}_i$ = state vector of i-th monosensor track,

$\hat{\mathbf{P}}_i$ = covariance matrix of $\hat{\mathbf{s}}_i$.

A schematic drawing of this fusion algorithm is shown in figure 3.1 for N=2, where $(\theta_m)_{1,2}$ represents the target measurements from the two sensors.

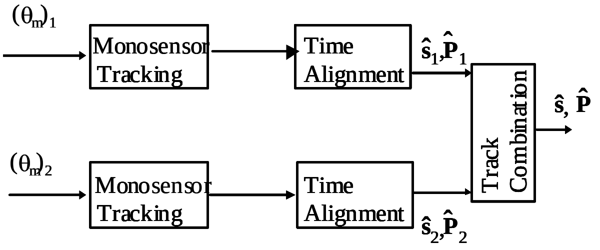


Figure 3-1 Multi-sensor filtering through combination of tracks

4. DE tracks management system

In order to apply the equations described in section 3, it is mandatory for the internal and received tracks of each tracker to be statistically independent. Therefore, each tracker has to internally maintain redundant state vector and covariance matrix information. Some details, regarding the "BT track" class diagram of the DE software, are reported in **Figure 4-1**.

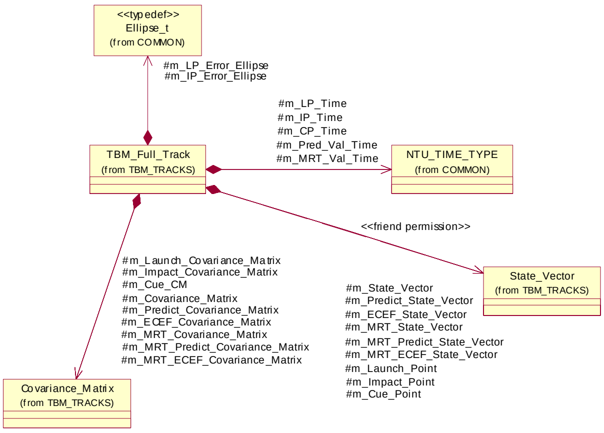


Figure 4-1 BT Track class diagram

5. Demonstrator description

The Multi-Radar Scenario Simulator allows simultaneous plots sending towards the tracker systems placed on Radar 1 and Radar 2.

BT track data, exchanged via a dedicated LAN (see **Figure 5-1**), are combined according to what described in section 3; the fused state vector is then used for IP prediction via a time-integration procedure.

Simulations data are written by the two tracker systems in independent files in order to be analyzed "off-line" by the Performance Evaluation System (PES).

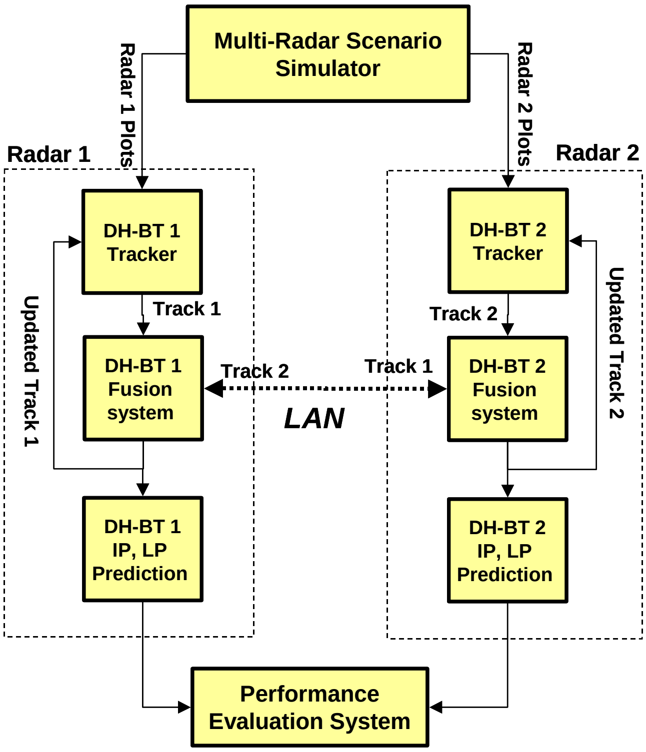


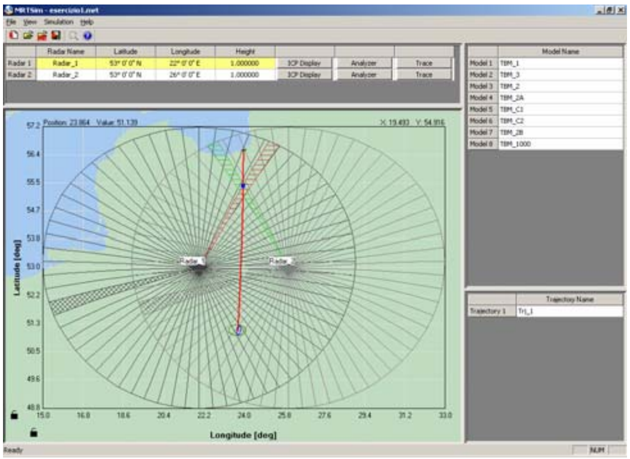
Figure 5-1 Demonstrator flow graph

The scenario creation, using the Multi-Radar Scenario Simulator (see **Figure 5-2**), consists of the following steps:

1. Radar modelling; for each defined radar, the set of characterizing parameters consists of: radar position; antenna initial azimuth; radar scan rate; instrumented coverage during surveillance activity and during dedicated tracking activity; probability of detection for different range sectors and operative mode; measurements errors (variances of zero-mean independent Gaussian distributions) for each operative mode; communication settings.
2. Trajectory generation; a database containing characterizing parameters for different BT models must be defined. For each BT trajectory, belonging to one of the defined models, the initial conditions (launch point, launch vertical angle and launch heading) have to be set.
3. Simulation settings; the number of Monte-Carlo trials and the number of scans for each simulation have to be defined.

During the scenario simulation, the following real time activities are performed by the Simulator:

1. For each Radar, at each beam-target coincidence, plots are sent according to the defined detection probability for the current operative mode;
2. Random noise (as specified in the scenario creation) is added before sending plots to each Radar;
3. Out of surveillance coverage, repointing messages (which in real systems govern the dedicated tracking beams pointing), sent by the trackers, are checked before sending the related plots.



	Radar Name	Latitude	Longitude	Height			
Radar 1	Radar_1	53° 0' 0" N	22° 0' 0" E	1.000000	ICP Display	Analyzer	Trace
Radar 2	Radar_2	53° 0' 0" N	26° 0' 0" E	1.000000	ICP Display	Analyzer	Trace

	Model Name
Model 1	TBM_1
Model 2	TBM_3
Model 3	TBM_2
Model 4	TBM_2A
Model 5	TBM_C1
Model 6	TBM_C2
Model 7	TBM_2B
Model 8	TBM_1000

	Trajectory Name
Trajectory 1	Trj_1

Figure 5-2 Multi-Radar Scenario Simulator

The Performance Evaluation System consists of a statistic analyzer which performs a set of computations after a Monte-Carlo simulation. **Figure 5-3** shows an example of the statistics of IP estimation, with the relevant theoretical and Monte-Carlo error ellipses.

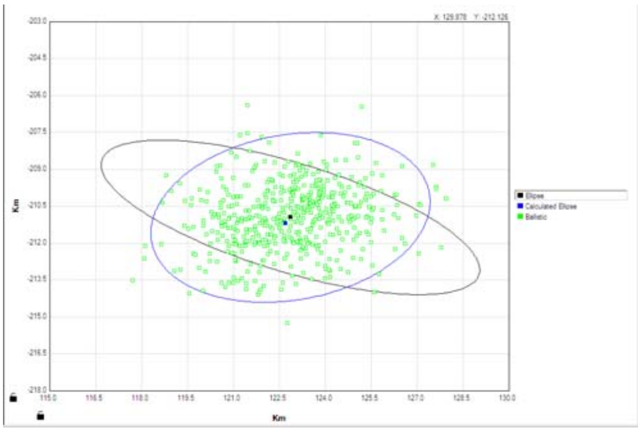


Figure 5-3 Output example of PES: IP error ellipses

6. Achieved results

In this section the system performances, evaluated via Monte-Carlo simulations, are shown. Two study cases have been considered. Both scenarios consist of two identical 3D long range surveillance radars whose coverage volumes are partially overlapped.

In the first scenario, a BT trajectory as depicted in Figure 6-1 and **Figure 6-2** has been inserted.

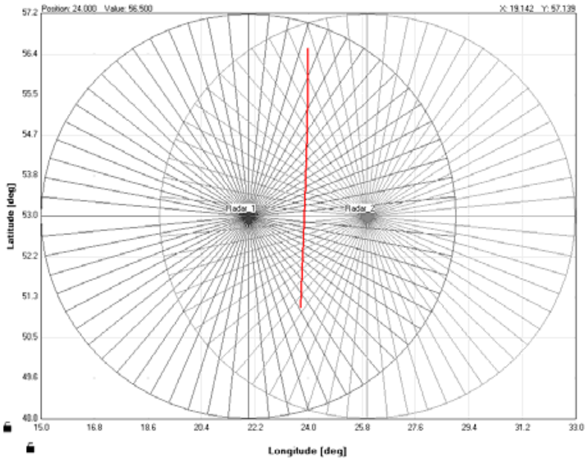


Figure 6-1 Sketch of Scenario 1

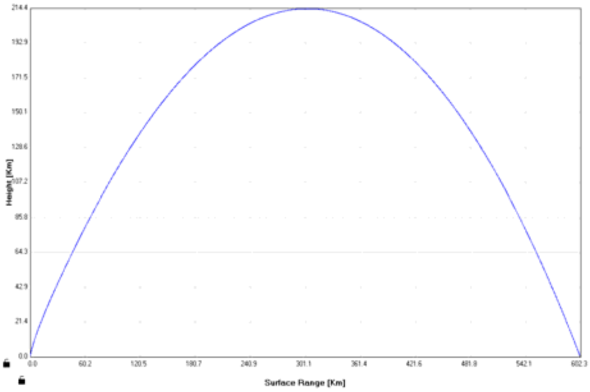


Figure 6-2 BT Trajectory of Scenario 1

The numerical results of 150 Monte-Carlo trials are reported in **Figure 6-3**. For sake of simplicity, are reported only the results of Radar 1 compared with fused ones. The geometrical symmetry of the proposed scenario implies that the results for Radar 2 are quite the same.

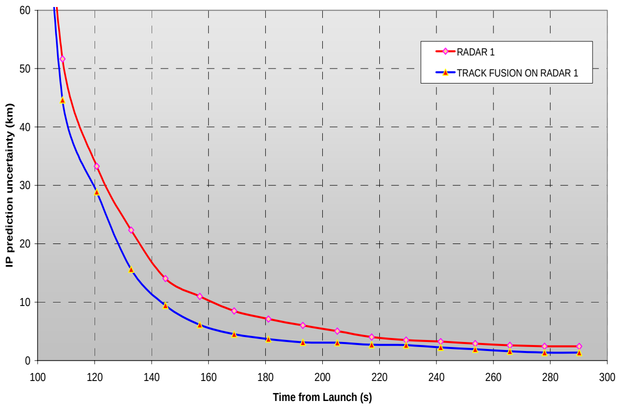


Figure 6-3 Scenario 1: numerical results

The average improvement (i.e. the average reduction in the half-major axis of IP error ellipse) is around 34%. The second scenario is shown in **Figure 6-4** and **Figure 6-5**.

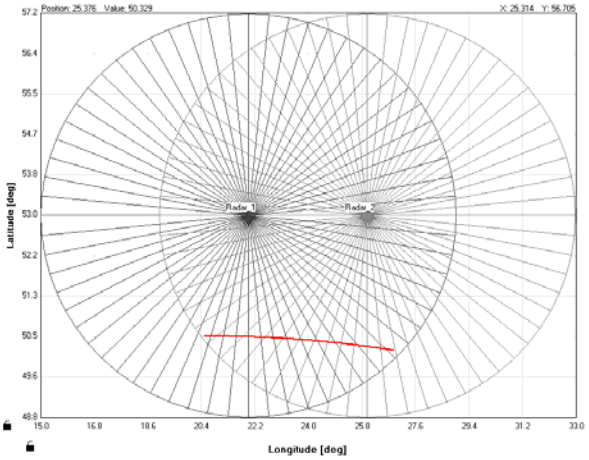


Figure 6-4 Sketch of Scenario 2

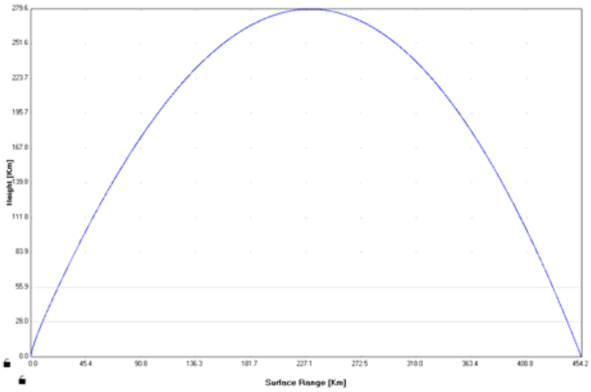


Figure 6-5 BT Trajectory of Scenario 2

The numerical results of 150 Monte-Carlo trials are reported in **Figure 6-6**. The geometry of the proposed Scenario implies a difference in the performances of the Radars (in fact, Radar 2 starts the tracking activity with a scan of delay). Nevertheless, the fused track is considerably more accurate than both of the single ones. The average improvement is over 40%.

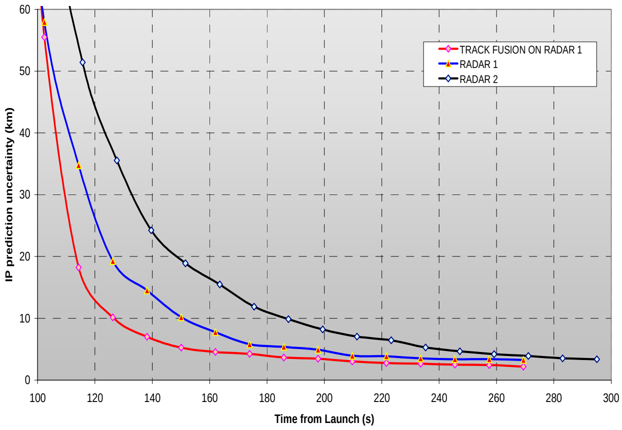


Figure 6-6 Scenario 2: numerical results

7. Conclusions

A track fusion procedure has been implemented in a test bed which uses the same hardware and software architecture of a real radar system. To this aim the following activities has been performed:

- a convenient and cost effective data fusion architecture has been conceived;
- a multi-radar scenario simulator with ballistic target capabilities has been realized;
- a communication network between the radars has been designed and implemented;
- the data extractor test bed has been modified in order to allow for multiple tracks fusion;
- a set of simulated experiment has been designed and used for testing the whole system performance.

It has been shown that the existing Radar DE hardware and software is capable of supporting the tracks fusion providing an average improvement in tracking accuracy around 35%. Let us remark that performing the track fusion directly on the Radar system and not in remote centers allows for side effect benefits; in fact, the tracking beam steering, which is directly controlled by DE, as well as IP and LP estimation, are greatly improved by having more accurate tracks.

8. References

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