5th International Conference from Scientific Computing to Computational Engineering
5th IC-SCCE
Athens, 4-7 July, 2012

AUTOMOTIVE RADAR AND SENSOR EARLY FUSION FOR DETECTING VULNERABLE ROAD USERS

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Keywords: Harmonic radar, automotive radar, track fusion, feature detection, VRU, ADAS

Abstract. *Vulnerable Road Users (VRU) usually have small radar cross-sections (RCS) and may be missed by conventional radars in a multi-target environment. Data fusion from more sensors and radars having different characteristics seems a promising solution to the problem. In this paper, we present the application of a radar/sensor fusion and processing architecture that combines the returns of conventional and harmonic radar and internal and external car sensors in order to improve the detection and tracking of VRUs. Road users (RU) having low RCS are not easily detected by the conventional radar returns, especially when they are very close to a larger RCS target. The harmonic radar returns are less affected by noise, clutter, or dense environments and focus only on RUs wearing harmonic tags (reflectors). By early fusing different radar types (conventional, harmonic, LRR, SRR) with other external or internal sensors (car dynamics, IR, etc.), a more accurate detection and tracking of the RUs is achieved, as well as, a proper classification of the detected VRUs at a higher Advanced Driver Assistance Systems (ADAS) fusion level.*

1 INTRODUCTION

Car accidents statistics in the E.U. show that accidents resulting in fatalities or serious injuries are mainly caused by collisions of cars with Vulnerable Road Users (VRUs) [1]. In an effort to reduce these numbers, Advanced Driver Assistance Systems are being developed to integrate traffic safety applications that exist or are currently under development.

As technologies supporting detection of crashes as they occur and reactions to them have matured, focus has been shifting towards technologies that will enable the detection and identification of potentially hazardous situations before crashes occur. One of the new techniques towards early-warning systems is the Harmonic Radar with Tags, which aims to complement conventional radars by revealing undetected vulnerable and other road users using wearable tags.

Such a technique involving the combination of conventional and harmonic radars, in parallel with several other sensor technologies, is the subject of the EC co-funded R&D project of the Framework Programme 7 "Reliable Application Specific Detection of Road Users with Vehicle On-Board Sensors" (ADOSE) [2]. Other technologies evaluated in ADOSE include Far InfraRed sensors, CMOS vision sensors, 3D range cameras and Silicon Retina Stereo sensors. ADOSE is part of an extensive effort towards the development of Advanced Driver Assistance Systems (ADAS). It deals mainly with the low-level of a typical ADAS, as shown in Figure 1 below. Specifically, the sensor device technologies and hardware, their refinement (including temporal and spatial common references) and feature extraction [2].

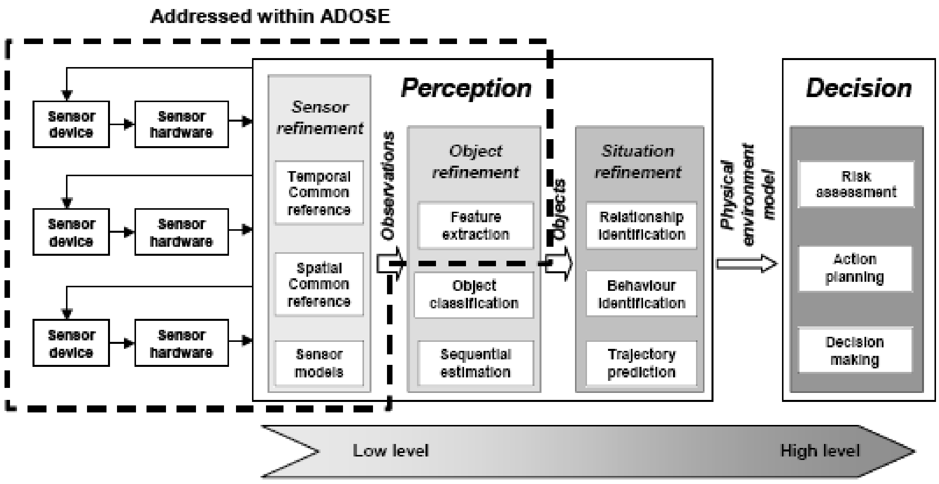

Figure 1. Data processing tasks of a typical driver assistance system and ADOSE objectives

2 THE AUTOMOTIVE HARMONIC RADAR

Radio detection and ranging (radar) has been widely used and is becoming increasingly popular for automotive applications. The preferred system for today's automotive applications is Frequency Modulated Continuous-Wave (FMCW) radar. The most important properties of radar sensors are the capability to measure the relative velocity of the tracked target, high robustness in varying weather conditions and the possibility for multi-target detection (depending on its resolution). Typical range & field-of-view (FOV) properties are 120–150 m & 8^o–15^o respectively for Long Range Radar (LRR) and 20–60 m and 30^o–60^o for Short Range Radar (SRR). The main concern in conventional radar systems is the ability to distinguish between clutter objects and road users or between multiple overlapping users.

An attempt to overcome this problem is presented with the use of Harmonic Radars and the corresponding Tags for the road users [3, 4, 5]. The term *harmonic* is used in radar systems to detect and localize small passive or active transponders, known as *tags*, that when irradiated with a certain radio (or microwave) frequency emits an harmonic frequency. This harmonic frequency is offset from the transmitted frequency and all the other echoes. When the proper receiving technique is used, the receiver can detect and localize the tags in dense clutter, where conventional radar system would typically fail. Road users, especially the vulnerable ones, may wear these special tags in order to become visible to such radars even in bad weather or traffic conditions (Fig. 2).

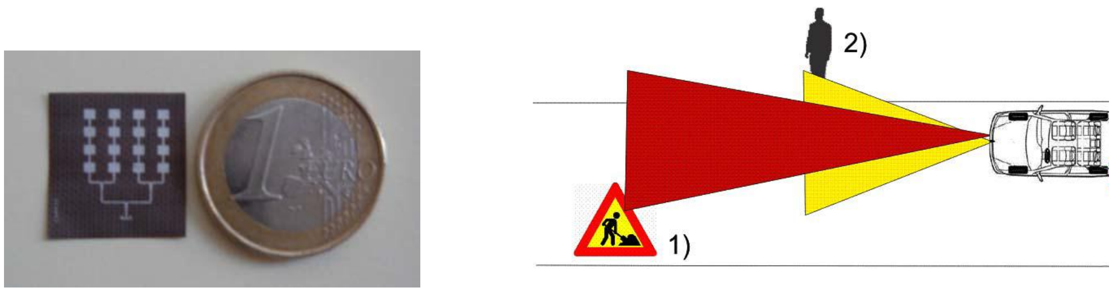

Figure 2. A wearable radar reflector (tag), and a use case of passive and active tag with harmonic radar: 1) Road block with active tag, 2) Person with passive tag.

Conventional and Harmonic radars may work together as complementary sensors (by complementing their Field of View), competitive sensors (for improved reliability and accuracy) or collaborative sensors (to derive new combined features). By combining conventional and tag returns, it is possible to detect more targets especially the smaller and vulnerable ones. Larger road users, clutter & noise often hide the smaller and Vulnerable Road Users (VRUs) from conventional radar. By attaching the harmonic tag, the road user becomes visible for the harmonic radar and easily detected and tracked by the accompanying Radar Electronic Control Unit (ECU) software.

2 THE AUTOMOTIVE RADAR DATA

The most important properties of radar sensors are, the capability to measure with accuracy the distance & the relative velocity of the tracked target, the high weather robustness, and, the possibility for multi-target detection depending on its resolution. In addition to these typical radar measurements, it is of great interest to develop radar data processing techniques that will extract additional features of a tracked object such as *shape, orientation, profile signature, size, maneuver intention*, etc.

Once the standard processing and combination of all radar data is completed, an accurate estimate of the target's dynamic properties becomes available and ready to be forwarded to other levels of processing or fusion technique. The raw radar data from the sensor itself, i.e. the complex waveforms as shown in Figure 3, still contain valuable information that remains to be extracted.

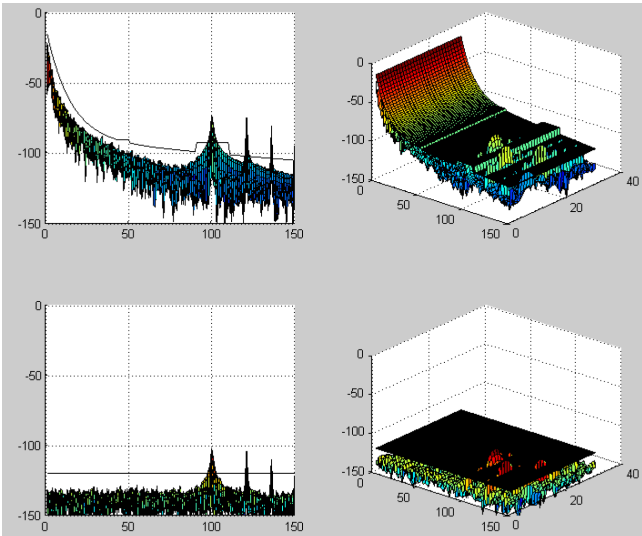

Figure 3. Simulated return signals from conventional (upper) & harmonic (lower) sensors

3 THE HARMONIC RADAR PROCESSING SOFTWARE IN THE ECU

Active sensors, like radar, focus on the geometric and dynamic properties of opposing road users, and, with the appropriate data processing support in ECU, produce excellent results regarding the position, velocity and the overall trajectory of opposing road users.

In this case, the aim of Harmonic Radar ECU software module (Fig. 4) is to: a) handle all radar returns either conventional or harmonic, LRR or SRR, as any typical radar processing software, b) integrate the car sensor data, and, c) combine and merge the results regarding tracks or objects.

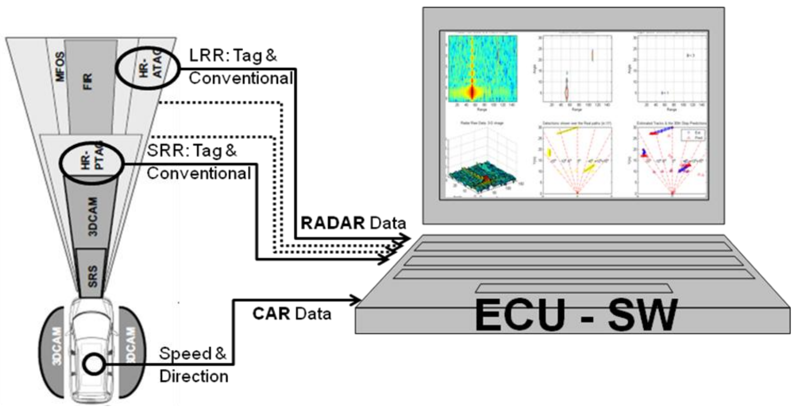

Figure 4. The role of Radar ECU SW in ADOSE

Therefore, the Radar ECU unit must perform a number of tasks on the raw radar data. The processing tasks of the designed software include: Data Alignment, Data Clustering and Segmentation, Feature Extraction, Data Association, Filtering, Track Management, Car data Integration, Early Fusion, and, Prediction.

3.1 Overall ECU SW Architecture

The architecture of the radar sensor processing & early fusion algorithm is modular and consists of several modules and sub-modules [6] (Fig. 5). The major modules include: the I/O modules, the measurement data pre-processing modules for each radar sensor, the car sensors module, the track maintenance, filtering, early fusion, and the track prediction modules, where:

- The I/O modules handle the data exchange between the Radar ECU and the sensors (radar or car), and the temporal alignment of the datasets.
- Data pre-processing extracts the basic features needed for creating the tracks of the Road Users including spatial alignment, noise/clutter reduction, "plot" detection & association.
- The track maintenance module, terminates and maintains all certified tracks.
- Early fusion combines all tracks derived from the different radars, integrates the car sensor data and creates a complete and more accurate representation of the situation.
- The tracking filter applies a filtering algorithm to estimate the current road user state. Filtering may also include smoothing in the past and predicting in the future for one or more steps ahead.

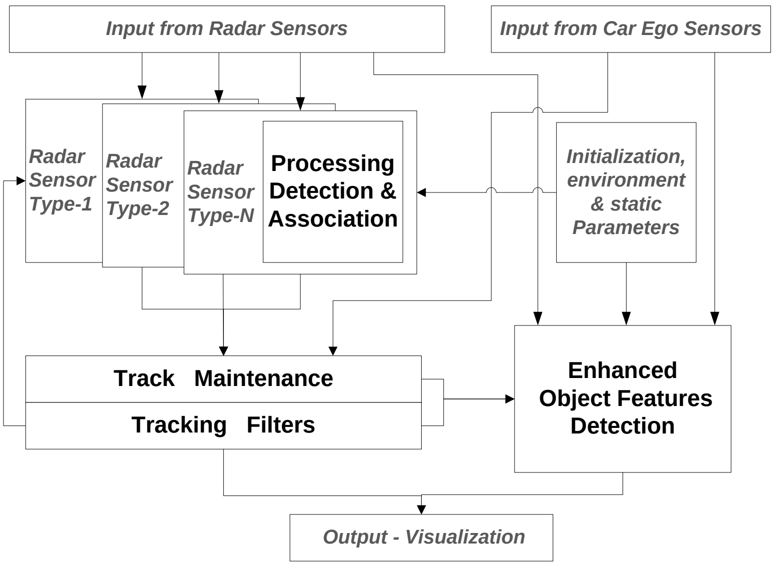

Figure 5. Overall Radar ECU SW architecture

3.2 ECU Software Core Modules

Pre-Processing Detection & Association

This step is responsible to reduce noise and clutter, extract target "plots" and create the correct pairs of real and predicted measurements. This is a problem of finding the best association between tracks and "plots" optimizing some criteria such as Generalized Nearest Neighbor (GNN) or Joint Probabilistic Data Association (JPDA) [7]. Typically GNN is adequate for the case of tracking under consideration.

Tracking & Forecasting

All confirmed tracks are estimated by a tracking filter such as Kalman Filter, Extended Kalman Filter (EKF), or even α-β-γ [8]. The basic Road User model used is the constant acceleration model that is adequate for most cases under consideration. More complex models can also be used in combination with adaptive or multi-model tracking filters [9], but at a higher computational cost. The use of tracking filters permits the calculation of the next expected measurement for each track as well as the size of a gate, an area where it is expected to appear. A tracking predictor based on the tracking filter is also implemented in order to forecast the future behavior of the

Road User and predict imminent impacts or dangerous trajectories. The Extended Kalman Filter (EKF) has been chosen as standard module since it handles the nonlinearities quite well. Conventional Kalman Filter and α-β-γ tracker were also implemented with satisfactory results for the specific case.

Enhanced Detection and Object Feature Extraction

For a Radar ECU each track corresponds to a Road User (object). The features typically extracted by the above procedures are position, velocity and maybe acceleration. In addition to these, there is also a number of advanced features that can be extracted from the raw radar data, the car data, etc., that may enhance the description and the properties of the tracked object. This is the role of a separate module. The design of such an intelligent system that extracts enhanced features from the radar data is based on adaptive and A.I. techniques and is presented as a separate work. The *enhanced feature extraction* module aims to identify the additional defining characteristics besides *position*, *velocity* and *acceleration* that will enhance our perception of the tracked object. These characteristics can be signal properties or behavior patterns such as: *shape, orientation, profile signature, size, maneuver intention*, etc [10, 11].

From each radar category a different set of information, regarding the Road User, will be extracted. The conventional radar returns depend on the size, orientation and reflectivity of the object, as well as, on its shape and its Radar Cross-Section (RCS). On the other hand, the harmonic radar returns depend on the reflecting tag, its size and orientation, and its technology (passive or active) or returned information. The estimated dynamics may also provide more information such as road user orientation, user dynamic model, user mobility status, etc., that can be extracted with the proper estimation & identification algorithms. Groups of identical reflections might also be determined, e.g. road barriers or intersections, even groups of pedestrians and their location with respect to road limits [12].

4 SIMULATION RESULTS

The developed radar ECU SW module processes all confirmed tracks through a tracking filter. Several tracking filters have been compared from a-b tracker to Kalman & Extended Kalman Filters, and the Kalman filter was selected for the specific implementation. The basic Road User model used is the constant acceleration model that is adequate for most cases under consideration. More complex models can also be used in combination with adaptive or multi-model tracking filters. In addition to the one-step-ahead prediction performed by the tracking algorithm, a longer forecasting may also be calculated according to our requirements.

Figure 6, presents the trajectories of two road users as they are processed by the Radar ECU SW module. The graph includes: the true position (black dots), the simulated sensor data peaks (circles), the detected "plots" (stars), the estimated position (diamond), and, the forecasts after 3 sec (triangles). From Figure 6, it is clear that after the 10th measurement (i.e. after 1 sec) the tracking filter detects the road-user trajectories and forecasts accurately their positions in the near feature (e.g., after 3 sec). This information will be used by an ADAS system to avoid an imminent collision.

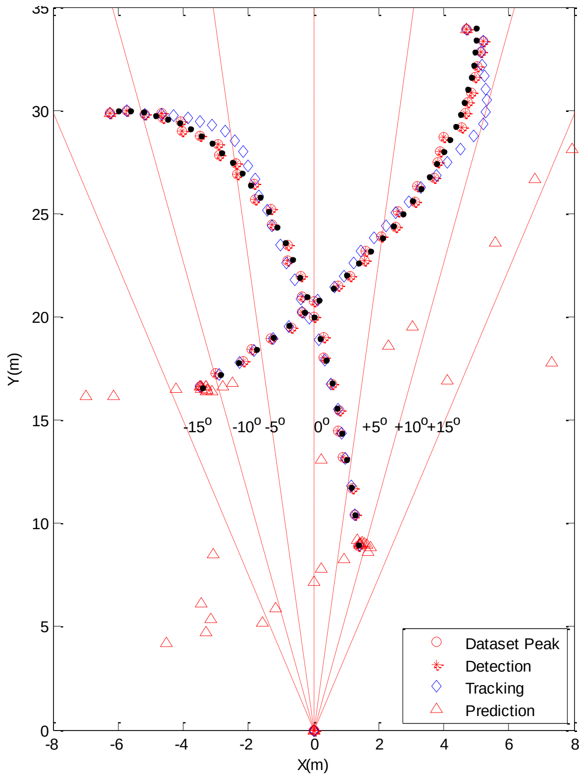

Figure 6: Tracking two turning & crossing Road-Users.

For the testing and evaluation purposes of the radar ECU, a separate GUI was created. The GUI facilitates the initialization of the ECU and provides visual representation of final & intermediate results. The GUI was developed using the MatLab GUIDE (GUI builder) and performs several analysis functions. A typical view of the GUI is shown in Figure 7.

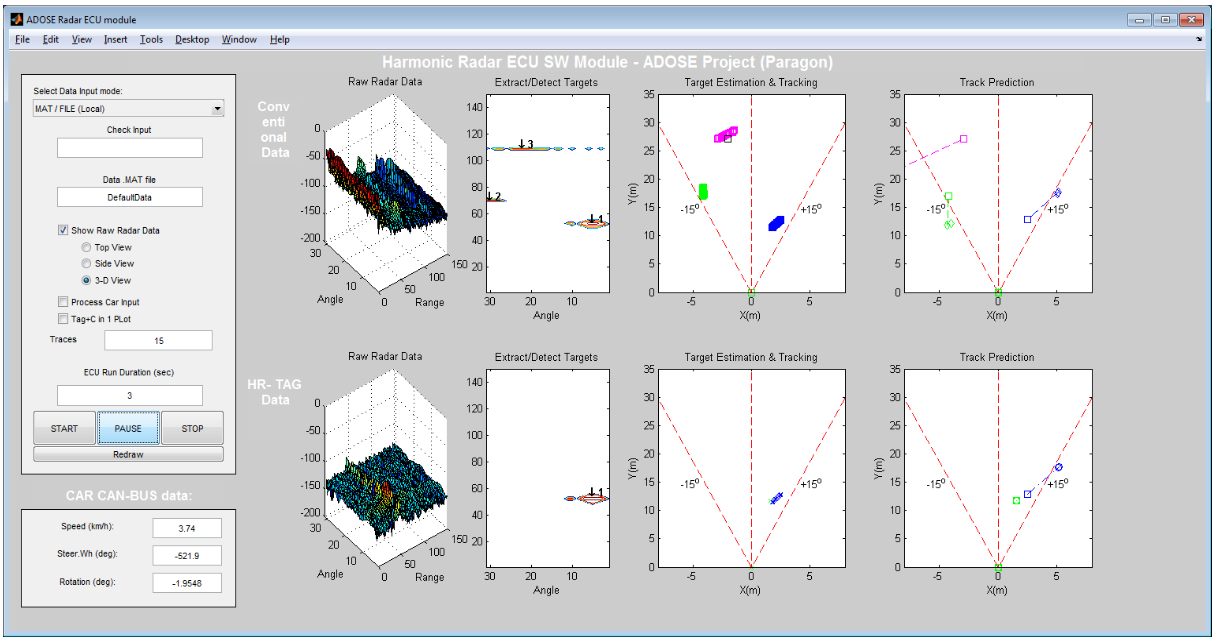

Figure 7: The Harmonic Radar ECU SW GUI.

The results of the ECU are presented on the right of the GUI, either separated per radar sensor, or, merged in one view (Figure 8). The split view presents the conventional, tagged, estimated & predicted results in four different plots. The combined view superimposes all ECU results in one plot.

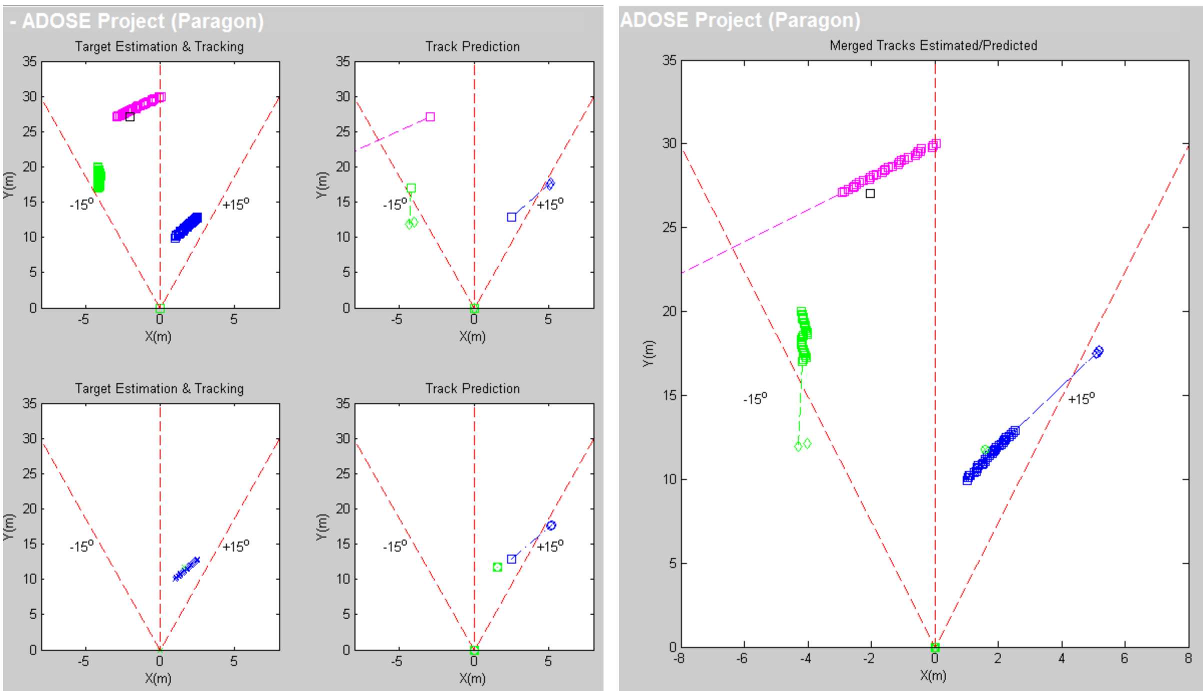

Figure 8: ECU Results Views: Separate for tracing & prediction per radar sensor (left), or, merged in one plot (right).

The Radar ECU software has been tested using simulated Radar returns (conventional and harmonic). The results of the combined data processing are shown below where, the conventional radar returns reveal, in general, all targets while the harmonic radar returns reveal the tagged targets only, but with increased accuracy. By combining both results the accuracy of common targets is improved, while any undetected target (the majority of VRUs have very low RCS) by one of the radars is introduced by the other radar (Figure 9). The tracking filter improves the state estimation of each track by reducing the estimation and prediction errors. The tracker finally converges in about 10 measurements that correspond to 1 sec of real time.

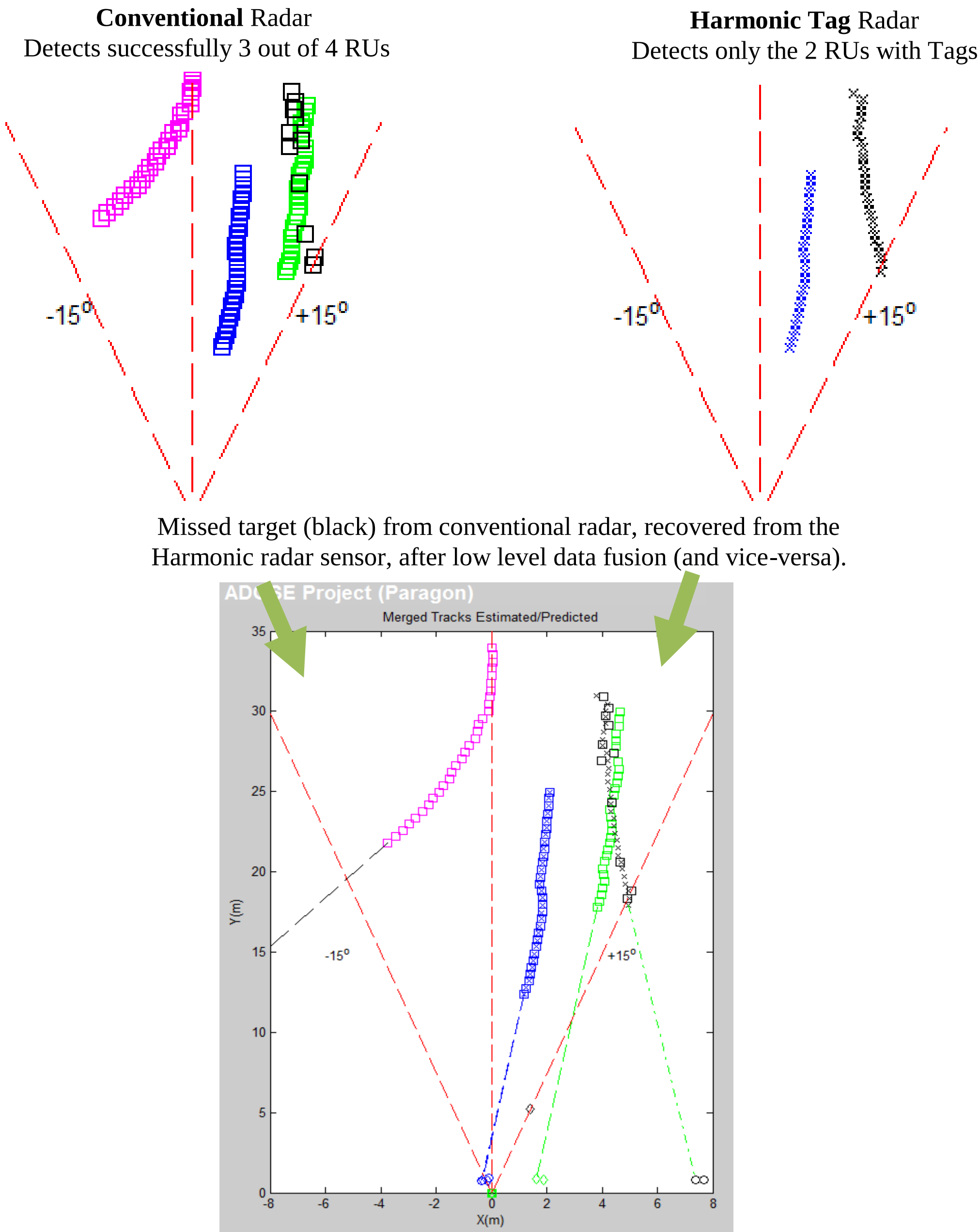

Figure 9: Radar Data fusion reduces miss probability

The developed Radar ECU software presented has been tested using simulated radar data and scenarios of variable complexity. Special tools have been applied or developed to support the testing procedure [13]. The final module is ready to be installed on an experimental vehicle, following the installation of a prototype Harmonic Radar developed also in the ADOSE project, for real data collection, and processing.

5 FURTHER FUSION OF RADAR ECU OUTPUT DATA

Radar-based detection and pre-processing by the Radar ECU produces a set of data that are subsequently forwarded to higher fusion levels or to other ECUs. This information typically contains data & parameters regarding the dynamic behavior of detected object, such as: position, velocity, direction, and acceleration. In general, radars provide the most accurate information about the dynamics of the detected object; therefore this information is invaluable for other sensor technologies where the accuracy on position or velocity is usually lower.

For example:

- By fusing the radar information about the position, velocity and direction of an object with the vision based information, new features or extra information is acquired (e.g. what we are facing, the front or the side of a vehicle).
- By fusing the combined radar-car information regarding object stationary property with the visually detected objects, any static/scenery objects can be ignored thus reducing the complexity of any subsequent calculation.
- By combining the horizontal 2-D grid of the Radar information with the vertical 2-D visual information a fused 3-D reconstruction of the scene is created, that may be further enhanced by other sensor information for a complete situation refinement.

Finally, Radar ECU tracking information about the detected objects is fused with other sensor tracking information to produce the high level object tracking. Radar tracking is a principal component for these procedures as it provides the most accurate values and predictions.

6 CONCLUSIONS

Systems such as ADAS, which incorporate different sensor technologies, require methodologies to determine and extract features from the signals of each sensor that will aid in the classification of objects identified in order to support automated risk assessment, action planning and decision making. The introduction of new sensors, such as the Harmonic Radar, in an ADAS system requires complex processing software architecture. The radar ECU, in addition to the classic detection and tracking tasks, must perform an early fusion of the complementary radar data to reveal undetected road users. The proposed Radar ECU software architecture is highly modular for easy maintenance and upgrade. It’s performance was successfully tested with simulated data sets of conventional and harmonic radars before implementation on a test-vehicle for track-testing.

Candidate methodologies for enhanced feature extraction were also developed. As soon as the first experimental data sets become available from the harmonic radar prototype currently under development, these methodologies will be applied and tested in practice in order to formulate the finalized enhanced object detection module of the harmonic radar ECU. The application of the proposed system is expected to improve the detection of Vulnerable Road Users (VRUs) and reduce the number of fatal accidents.

ACKNOWLEDGMENTS

The work presented in this paper has been performed under the EU-funded R&D project ADOSE with contract number P7-ICT-2007-1-216049.

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