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IMPROVED RADAR DETECTION AND TRACKING OF VULNERABLE ROAD USERS

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Abstract: *In this paper, a radar data-processing architecture for advanced automotive radars is presented. The main goal is to improve upon the performance of conventional automotive radar technology. This will enable, among other things, the improved detection and tracking of Vulnerable Road User, who usually have small radar cross-sections and may be missed by conventional radars in a multi-target environment. To overcome this obstacle, an advanced automotive radar combining the returns of conventional and experimental harmonic radars is proposed. The advantage of harmonic radars is that their returns are less affected by noise, clutter, or dense environments due to the use of tags. The radar returns from the two radars are simultaneously processed by an Electronic Control Unit. This unit handles the temporal and spatial alignment of the radar returns, detects and associates the target plots, maintains the verified trajectories and predicts the future position of road users. The unit's output is designed to be integrated in a full Advanced Driver Assistance System processing chain that will fuse the outputs from various sensors and will assess risks, plan actions and make decisions to assist drivers to avoid potentially hazardous situations.*

1 INTRODUCTION

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). 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). 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 [1].

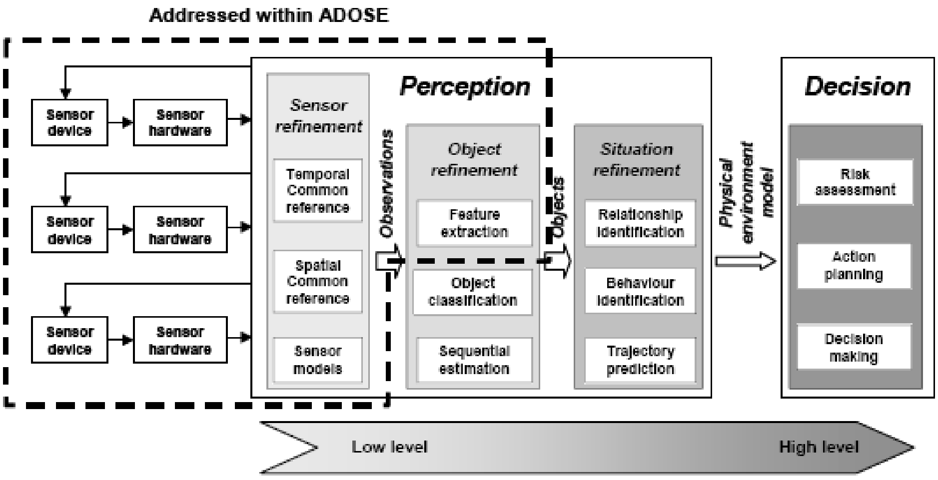


Figure 1. Data processing tasks of a typical driver assistance system and ADOSE objectives

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 [2-4]. 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).

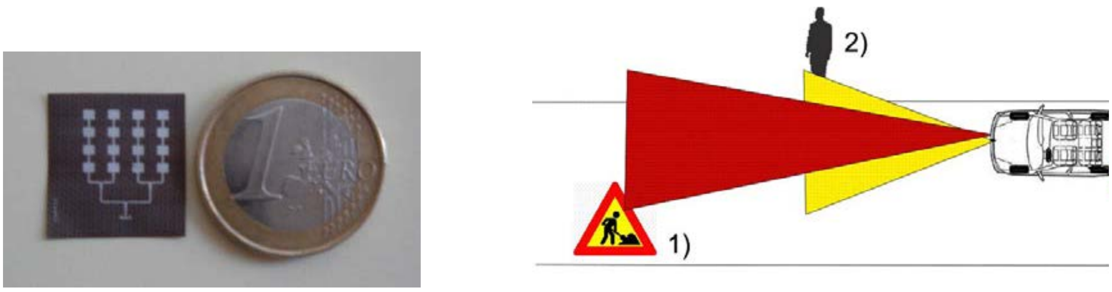


Figure 2. A wearable radar reflector (tag), and a use case of passive and active tag with harmonic radar: 1) Road block with active tag, 2) Person with passive tag.

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.

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. 3) 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.

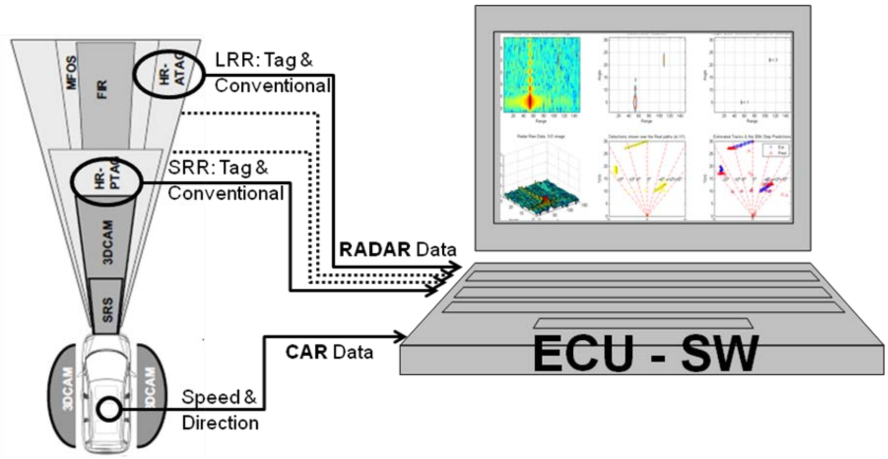


Figure 3. The role of Radar ECU SW in ADOSE

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 (Fig. 4). 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.

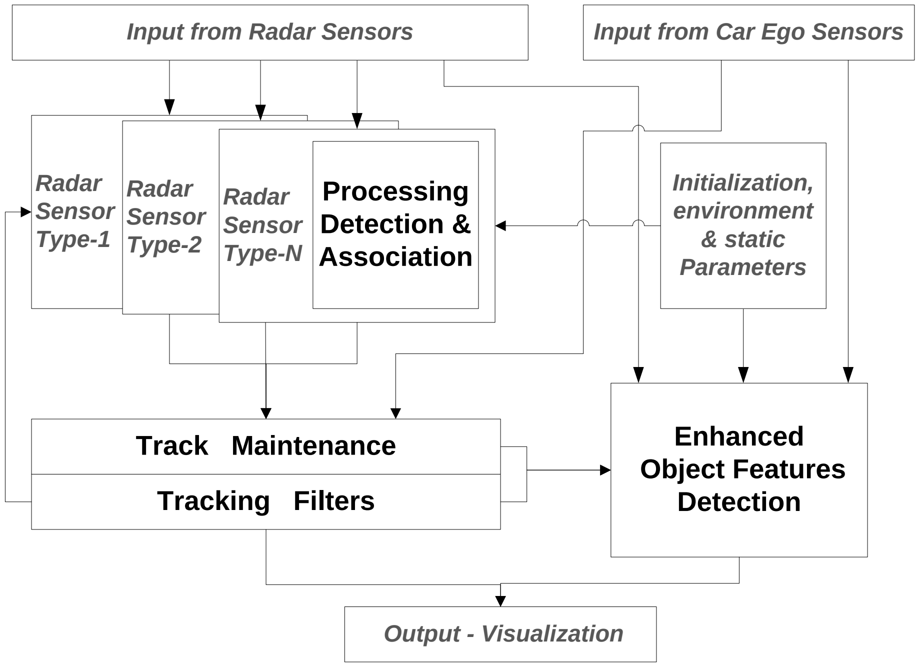


Figure 4. Overall Radar ECU SW architecture

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 (Fig. 4). 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) [5]. 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 [6]. 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 [7]. 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 (Fig. 6).

Enhanced Detection of Object Features

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.

4 SIMULATION RESULTS

The Radar ECU software has been tested using simulated Radar returns (conventional and harmonic). A sample of the raw radar data is shown in the Figure 5. In the same figure is also demonstrated the use of different thresholds, linear, exponential or adaptive. The top two graphs show the returns from the conventional radar, which is characterized by near-exponential rise in noise (in dB) the closer one gets to the radar sensor (distance in metres). The bottom two graphs display the returns from the harmonic radar, which in contrast show a distinct absence of noise compared to conventional radar.

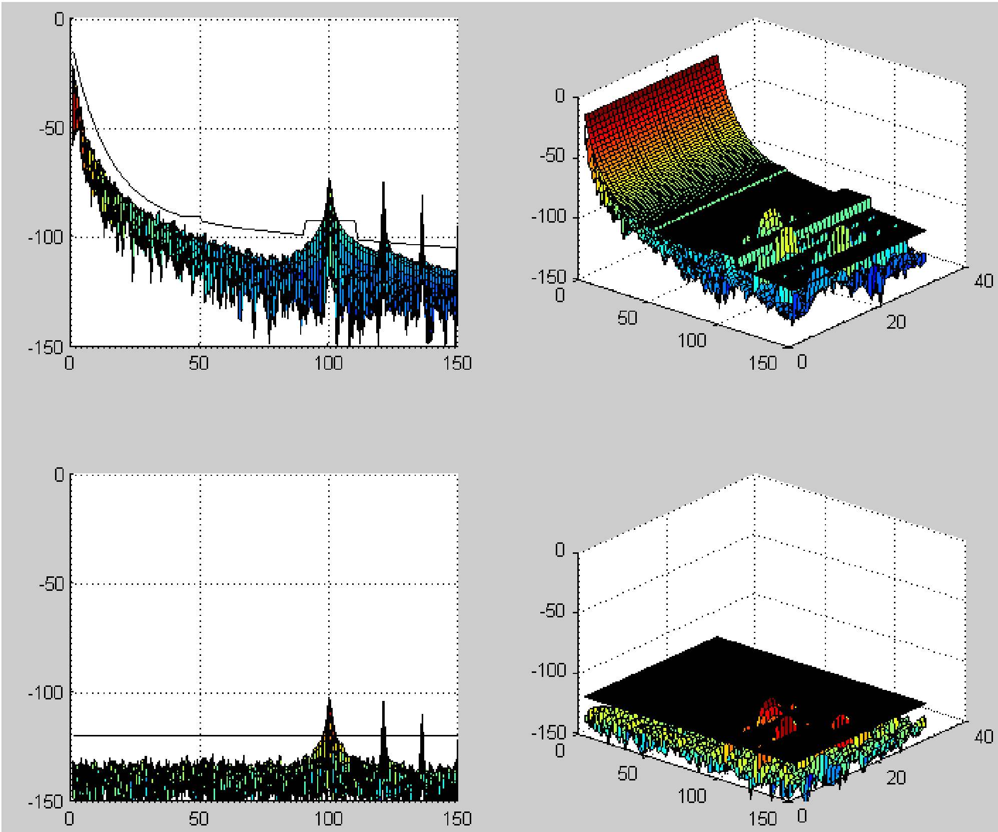
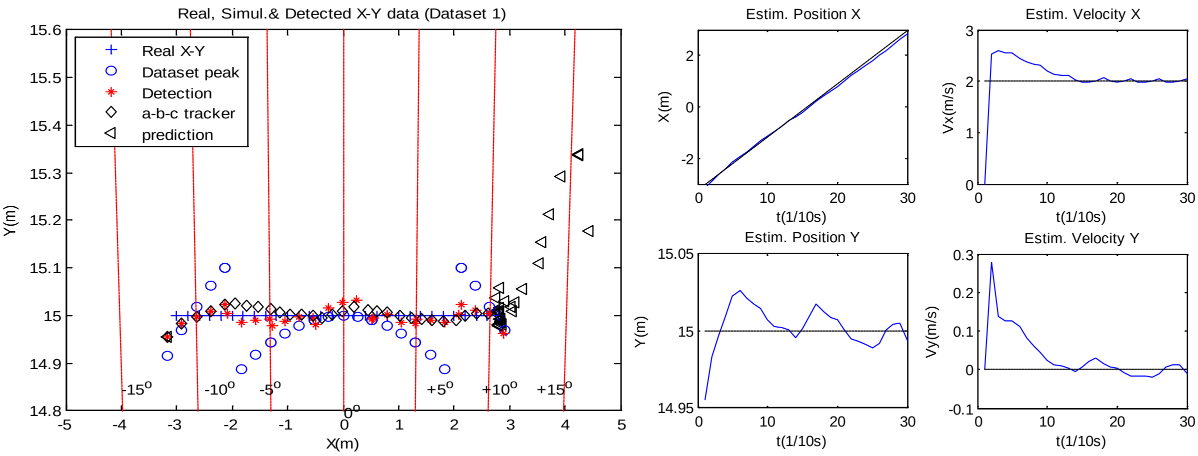


Figure 5. Simulated return signals from conventional (upper) & harmonic (lower) sensors

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 by one of the radars is introduced by the other radar. (Fig. 7)

The tracking filter improves the state estimation (Fig. 8a) of each track by reducing the estimation and prediction errors (Fig. 8b). The tracker converges in about 10 measurements that correspond to 1 sec of real time.



(a) (b)

Figure 6. Tracking filter performance: a) Filtered & predicted results, b) Position & velocity errors.

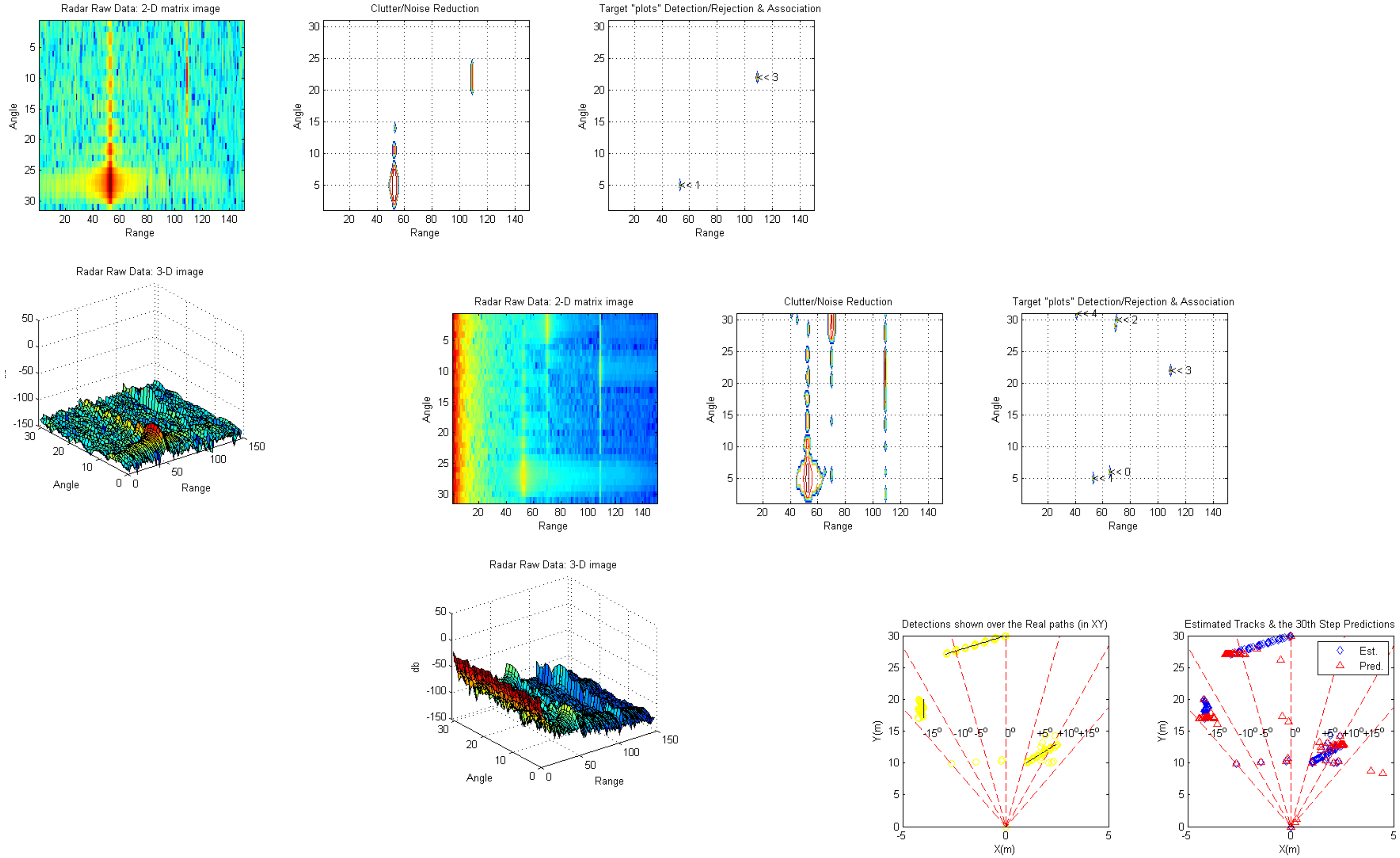


Figure 7. Combined detection & tracking from conventional & harmonic sensor

5 NEXT STEPS

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 [8]. The final module remains 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.

6 CONCLUSIONS

The introduction of new radar sensors, such as the Harmonic Radar, in an ADAS system requires more complex processing software architecture. The new Radar ECU, in addition to the classic radar 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.

7 ACKNOWLEDGMENTS

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